NUCLEAR ENGINEERING VOL. 4 NO. 38 MAY, 1959

U.K. Nuclear Ship Policy

TO DATE only one nuclear-powered merchant vessel—the "Savannah"—is under construction. Powered by a single pressurized water reactor, she will not be economically competitive in any sense of the word. Her value as an experimental plant is open to question and her significance in terms of prestige has yet to be assessed. It can be argued that to appreciate fully the implications of applying nuclear reactors to marine use, practical construction and operation are necessary exercises, but it is easy to exaggerate both the difficulties of installing a reactor in a ship and the value of the experience gained by doing it once. Control and emergency problems are different from land-based plant, but these must be largely resolved before any building begins.

From the great number of marine studies that have been made throughout the world, the conclusion must be drawn that no reactor system is ready for immediate competitive marine application. A return to fundamentals then is clearly indicated and, in this context, fundamentals imply fuel and fuel cycles. Particularly in countries outside America, it would seem that any reactor system for marine use must be based upon the burning of plutonium. In the United Kingdom alone, civilian power stations will be producing some 400 kg Pu annually by 1966 and this amount will progressively increase through the years. B.S.R.A. have a small team at Harwell studying the fundamental problems of burning this material, not from the metallurgical point of view, but from the physics. There is still a great deal of basic work to be done in this field, to determine, for example, the rôle that Pu^{240} might play as a burnable poison, and although the Authority is also concerned with the broader aspects of using plutonium as fuel, the total effort on this side of the Atlantic would appear to be small. At the Andrew Laing lecture to the Institute of Marine Engineers last October, Sir John Cockcroft stated that reasonable fuel costs could only be achieved by using the plutonium by-product from the future generating authority's reactors. Until the basic physics of plutonium fuel systems have been evaluated together with their related safety problems, the choice of a particular system can scarcely be made. But, certain of the problems are specifically marine and an early evaluation cannot be made by waiting for the relevant data to emerge from the power station programme which is the chief concern of the AEA.

When the time comes, either because technically we are in a position to anticipate a continuously developing building programme or because our hurt pride can no longer bear being land-locked, then the problem of financing and organizing the prototype must be resolved. It were better indeed that this were done now, rather than that it be left in the air. The AEA must clearly take the major part in the initial studies leading to the recommendation of the reactor type and its subsequent engineering. Both the Admiralty and industry have major interests in the detailed development of the power unit and in the design and construction of the ship. For naval work, long range is an intrinsic advantage and nuclear-propelled naval vessels will be justifiable before nuclear merchantmen. The Admiralty has also a considerable force available for operational experiment, and it is logical therefore that the Admiralty should finance the constructional project and run the first prototype ship whilst the AEA finances the bulk of the development of the reactor system.

Industrial Participation

We must not lose sight of the prime objective of building a prototype, that is, to provide all interested parties with the maximum experience. The ship should have direct civilian applications and the obvious choice is for a fleet tanker of about 40,000 tons. It would be pointless if such a one were designed by the AEA and the Admiralty and operated by the Navy, unless industry had full access to experimental results and know-how through all the stages of the project.

This does not mean theoretical access to that part of the information which one of the main parties arbitrarily decides to de-classify, but implies know-how gained from working on the project.

Now is the time to start building up a team. Let invitations be issued to all sections of industry, including reactor designers and constructors, the shipbuilders and shipowners and the insurance interests to second personnel (and pay their salaries) to a team which will be integrated into one major development and design group answerable to the Government. The Admiralty and the AEA would be asked to place at the disposal of the group appropriate funds and facilities. Initially the group would be subdivided into a number of sections able to study fundamental problems, and once the preliminary basic work had been completed a number of competitive designs could be drawn up. From these, one would be selected for detailed development and the ship and its components would then be built, presumably

as the result of competitive tendering. This may introduce embarrassment due to the need for manufacturing companies to entertain designers based perhaps on a competitive company, but this problem should not be insuperable, particularly if the design group has worked out complete, detailed engineering drawings.

Implicit in such an arrangement would be an agreement that all patents resulting from the design study would be available at least to all companies that had sent representatives, and provided this principle was established at the outset, there should be no inherent difficulties. The supreme head of the organization must be a man of considerable qualities, able to co-ordinate and progress the efforts of a widely varied group, but such men can be found. It would be necessary to give him wide executive powers and to define at an early stage in the project, a programme of development that was both realistic and stimulating. What the United Kingdom needs more than a stop-gap building programme is a clearly defined policy executed by a broadly-based development team given as a single objective, an economic nuclear-powered merchant ship.

Fast Reactor Programme

BEGUN in March, 1955, the Dounreay fast reactor is now scheduled to go critical sometime in June. At the present time the circuit is being filled with sodium and the system checked for integrity, while the circulation system is commissioned. Originally planned to be operational at least 12 months ago, the DFR project has suffered both from technical setbacks and a decrease in urgency.

Ten years ago it was feared that reserves of uranium were relatively small and there was, therefore, a basic urge to develop a reactor system which would give the highest possible burn-up of natural uranium fuel. Although, theoretically, provided the conversion factor is greater than unity, complete burn-up of U^{238} is possible, in practice the ratio should be significantly greater than one, as at each stage of fuel processing, some of the fissile material is lost and to avoid an intolerably large fuel investment and prohibitive processing costs, the gain per cycle must be high.

The past decade has, however, seen a great change come over the uranium ore industry and, apart from strategic considerations, the short-term urge to develop a reactor system with a high conversion ratio is small. Present estimates of known uranium reserves which can be exploited commercially would indicate that, even with low conversion ratios and complete rejection of burnt fuel, there would be no world shortage in the next 30-50 years.

On the face of it the fast reactor system simplifies a number of engineering problems. In the core, low cross-sections would appear to permit a wide choice of constructional materials, but in reality light materials must be avoided because of their moderating properties, through elastic scattering and, at the same time, heavy elements should be avoided because of the effects of inelastic scattering, otherwise degradation of the spectrum results. This is an important factor when extrapolating from zero energy reactors to power reactors. A breeding ratio of two has been demonstrated in critical assemblies such as ZEPHYR but whilst the peak of the fission spectrum is in the region of 1 MeV, the average spectrum for low-power reactors is nearer 0.1 MeV and in a big-power reactor an even lower value must be anticipated. The greater the power density of the reactor, then the smaller is the conversion ratio and the longer is the utilization cycle, resulting in greater losses in processing and higher fuel costs.

It must be remembered also, when considering the fast reactor programme, that operational temperatures are high and, with liquid metal cooling, much new ground has had to be broken. A particular problem has been the oxygen content of the sodium both as regards measurement and specification of maximum levels in order to eliminate corrosion troubles. A certain background of experience has been available at lower temperatures, but extrapolation of the data available to higher temperatures leaves many uncertainties.

Safety Problem

One of the major factors governing the relatively slow progress in the completion of the design is that of safety and control, emphasized by the run-away of the first core in EBR-1. It now seems fairly certain, and tests on the new EBR-1 core should conclusively prove this point, that the super-critical condition produced in the first core resulted from geometric distortion, an effect which, once known, can be guarded against by proper design. The core of the DFR is a highly complex piece of engineering requiring a great deal of precision work on a grand scale, but construction for the most part has proceeded according to schedule.

The greatest hold-up has, apparently, resulted from a shortage of effort, latterly due to the reorganization within the Authority necessary to implement the Fleck Committee's recommendations, but due also in no small measure to the reduced confidence in the ultimate future of the system.

Notwithstanding its limitations, the fast reactor does hold the promise of the lowest capital cost per installed kilowatt of any system and is the most optimistic approach to the efficient burning of plutonium. There remain many serious engineering problems to be solved, as, for example, the design of an economic heat exchanger, and solid fuels may need to be replaced by liquid fuels, but the importance of low cost and plutonium fuelling for nuclear stations to be built in the 1970s cannot be overestimated. Less developed systems may look attractive (as did once the HAR), but it would be foolish not to consolidate the considerable effort that has already been expended. The most pressing requirement is for a resurrection of faith associated with an increase in the effort placed at the disposal of those responsible for development.

DIGEST...

Surveying Significant News

London Exhibition Attracts Nuclear Exhibitors

Considerable interest has been shown in the nuclear section of the Engineering, Marine, Welding and Nuclear Energy Exhibition held in London this year at Olympia from April 16-30. This is the second time the nuclear industry has been represented at this exhibition, the first was in 1957, and the increased response is a good indication of the growth of the industry (see pages 220 to 226).

Japan Decides on G.E.C. Design; Concludes Fuel Agreement

Following the despatch of a letter of intent to G.E.C./Simon-Carves covering the contract to build a 150-MW gas-cooled graphite moderated nuclear power station at Tokai Mura, Japan (pages 204-205), agreement has been reached between the Japan Atomic Power Company and the AEA for the supply of fuel for the reactor. The first delivery, for the initial fuel charge, will be about 200 tons of natural uranium, the cost of which has not been divulged but is believed to be roughly £21,000 a ton. At the same time Dr. Ipponmatsu of J.A.P.C. has signed an agreement for technical assistance with the AEA.

IAEA Drafts Manual Covering Isotope Transportation

The co-ordination at an international level of safe practices for the handling of radioactive materials has moved another step forward by the announcement of the IAEA that they have reached provisional conclusions on safety requirements for the transportation of radioisotopes and radioactive ores and residues. The provisional conclusions, which have taken into account the growth of the use of radioactive materials throughout the world, will now be sent to governments and organizations concerned, for comment.

Ispra Research Centre Opened

The Italian research centre at Ispra was formally opened on April 13 by President Gronchi. The centre, which is operated by CNRN, occupies 340 acres on the eastern shore of beautiful Lake Maggiore and includes a 5-MW, CP5 reactor in a gas-tight metal cylinder 79 ft high. The Italian programme of development calls for an installed nuclear capacity of 500 MW, represented by four power plants, within the next five years. At present only the N.P.P.C.-Agip Nucleare 200-MW plant at Latina is under construction although work on the SENN station (re-named Garigliano, and described on pages 200-203) to be built by I.G.E. is due to begin shortly.

AEC Investment in Protection Research

Recent statements by Mr. John McCone, Chairman of the AEC, show the magnitude of the U.S. investment in protection research. The Commission plan to spend this year $18 million in research on problems associated with radiation standards and protection; $2.5 million will be spent on sampling and analysis for national and world fallout studies, and a further $450,000 will go on fellowships for training in health physics, industrial hygiene, etc. A general increase in these expenditures will take place with the 1960 budget.

Atomic Industrial Forum's Liability Study

Atomic Industrial Forum, a national association of the U.S. nuclear industry, has published suggestions to solve international nuclear liability problems. The report, *International Problems of Financial Protection against Nuclear Risk*, is based on a study conducted under the auspices of the Forum and the Harvard Law School by a Harvard research team under Mr. R. B. Eichholz, a former counsel to the U.S. foreign aid programme. This is the second American major independent effort on the liability problem and should play a large part in the eventual formulation of laws. The first study was done by the Legislative Drafting Research Fund of Columbia University and was devoted mainly to domestic aspects.

Euratom and U.S. Modify Patents Agreement

An important section of the U.S.-Euratom agreement, that of patents, is likely to be very much revised following discussions now taking place on the joint research and development programme. Reluctance, mainly on the part of U.S. industry, to give up patents has meant revising the agreement which will probably evolve into a system whereby private firms and Euratom will share royalties. Announcements on the building of U.S. type nuclear plants in Euratom countries are expected to be released soon.

IAEA and Japan Agree Uranium Supply Price

The agreement for the first purchase of nuclear fuel from the IAEA has now been signed in Vienna, beginning what is hoped to become a large movement of fuel from member countries via the Agency to buyers. Japan is the first buyer, and will receive three tons of natural uranium for use in a research reactor at $35.50/kg. This price has been established by taking into account the bids made in response to the Agency's invitations to tender for the supply of fuel, plus handling charges.

CNRN Budget Halved

Following the Ispra opening, the allocation of only half of what they asked for in their 1959-60 research budget has come as a severe disappointment to CNRN. But at the same time it must be appreciated that the Italian Government have allowed them half of the total budget of research expenditure which, in itself, constitutes 64% of the total budget of the Ministry of Industry. The sum given to nuclear research is 5,000 million lira.

Over $80 million Worth of Nuclear Equipment in One Year

A joint survey undertaken by the Bureau of the Census, Department of Commerce, and AEC, gives an indication of the extent of industrial participation in the U.S., in the nuclear energy programme. In 1957, shipments of radiation detection and monitoring devices amounted to more than $16 million and shipments of reactor vessels and tanks were above the $10-million mark. Instrumentation for reactor control came to $9.5 million and $8.6 million was spent on complete fuel elements. Nearly another $40 million made up the rest of the expenditure. This represents a considerable increase on the 1956 figures.

Fuel Element Produces Electricity by Direct Conversion

Direct conversion of reactor heat into electricity has been demonstrated at Los Alamos. Basically a thermocouple formed between a uranium carbide fuel element and a surrounding plasma of cæsium, vaporized by the reactor heat and ionized by the radiation, a 3 ft high assembly inserted in a fuel channel has produced tens of watts for several hours. The development team headed by Dr. Grover believes the system will have an application as auxiliary power sources in space vehicles. Suggestions that it can eventually displace the conventional thermal cycle are for the present highly speculative.

Oxide Fuelled Fast Reactor Project

The U.S.AEC is negotiating with General Electric a development and design contract following the company's proposal for a fast breeder reactor operating on a plutonium oxide-uranium oxide fuel cycle. The proposal was selected from eight received in response to an invitation issued last October. Initial value of the cost-type contract is expected to be $500,000 and covers a period of 18 months.

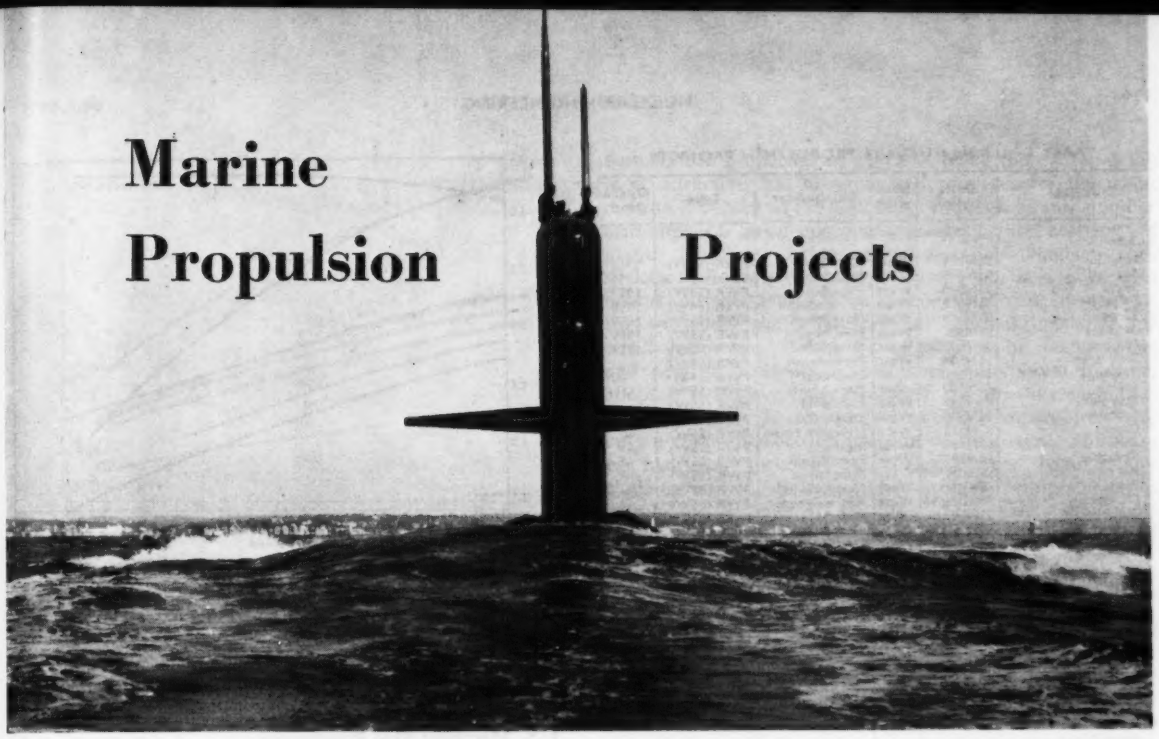
Graphite Machining Facilities in the U.K.

Three new graphite machine shops are now working on moderator components for Bradwell, Berkeley and Hunterston nuclear power stations (pages 206-215 this issue). A fourth facility is expected to start up in a few weeks on the graphite required for Hinkley Point. At the same time, the old graphite machine shop at Windscale will become partially redundant as it will then have completed all the components required for the four Chapelcross reactors.

Reactor Briefs

The 5-MW CP-5 type research reactor at the Italian research centre, Ispra, near Milan, has begun operating. . . . AEC's 1-MW tank-type medical research reactor at the Brookhaven National Laboratory achieved criticality on March 15. . . . 1-MW pool-type research reactor at the McMaster University, Hamilton, Ontario, started operating on April 8.

Marine Propulsion Projects



BY far the most formidable nuclear ship-building programme in the world is that of the American Navy. At an early stage in nuclear developments, the U.S. decided that nuclear-powered submarines represented a new and important weapon and an intensive building programme was instituted. Initially two reactor systems were regarded as holding promise. The first of these, the pressurized water reactor, which powered the first nuclear submarine, the " Nautilus," has finally been adopted as standard, the second system which was sodium cooled, and was initially installed in the " Seawolf," gave trouble and the system has, for the time being, been abandoned. It should be noted that the S2G's trouble was largely in the engineering external to the reactor and did not arise directly from nuclear difficulties.

Two other countries are known to have naval ship projects, the U.K. and France. The U.K. " Dreadnought " project for a nuclear submarine has passed through a number of phases, but in the past month or two the situation has been crystallized. Modifications to the exchange agreements between the U.S. and the U.K. have allowed access to U.S. Naval development and an agreement was concluded recently between Rolls-Royce of the U.K. and Westinghouse of America for the purchase of a propulsion unit of the type installed in the U.S. submarine " Skipjack," (illustrated above) in addition to manufacturing know-how. The ship will be built at the yards of Vickers in Barrow and should be ready for sea in the early summer of 1961.

A complementary development programme is also under way, leading to the building (which is due to begin shortly) of a land-based prototype submarine propulsion unit on a site adjoining the AEA's Dounreay establishment. This prototype is being engineered in the U.K. although the core will be based largely on American experience and will closely resemble the " Dreadnought " core. The design includes a number of important experimental features, aimed at improving efficiency and cutting down the capital cost of the plant. The reactor will be used for the training of naval crews and a long research programme has been drawn up to study fuel behaviour and to investigate, for example, the use of burnable poisons. No pronouncement has been made concerning the building of other U.K. naval nuclear-propelled vessels, but it is unlikely that the Admiralty will be content with one sea-going submarine.

To provide training for naval personnel, a department has been set up at the Greenwich Royal Naval College, where future crews will receive basic fundamental training in nuclear engineering and will be academically equipped to handle the new technology. It is likely also that the course will be extended to cater for naval design engineers, and interested commercial organizations. Already a team destined to operate the " Dreadnought " has received preliminary training at Greenwich and is now in the United States obtaining first-hand experience.

In France, the state of the Q244 nuclear submarine project is less clear. It is understood that negotiations have been going on for some time between France and the U.S. concerning the exchange of information and recently it was made known that the original plans for using natural uranium rather than enriched uranium have been abandoned. It is likely that at least one pressurized water reactor unit will be installed in a submarine and that construction work will start this year. It is not known how far advanced plans in the U.S.S.R. are for the establishment of a nuclear-propelled fleet.

Non-naval Craft

The exploits of the " Nautilus," and later the " Skate," which have demonstrated unequivocally the practicability of nuclear propulsion and have shown what vast cruising distances are possible, have done much to stimulate interest in the potentials of nuclear propulsion for merchant ships.

The problems are, however, markedly different, notably in the importance of economics. No figures have been published of the running costs of the American submarines, but they are known to be considerably higher than would be expected if they used conventional propulsion systems.

The world's first nuclear-propelled surface ship is the " Lenin," which is about to leave on her maiden voyage. This Russian icebreaker is powered by three pressurized water reactors and is designed for a cruising speed of 16 knots and is capable of opening a seaway through ice 6 ft thick. The special working conditions of this icebreaker again make economics of secondary importance and there is little doubt that operational costs will be very much higher than would be obtained from either diesel

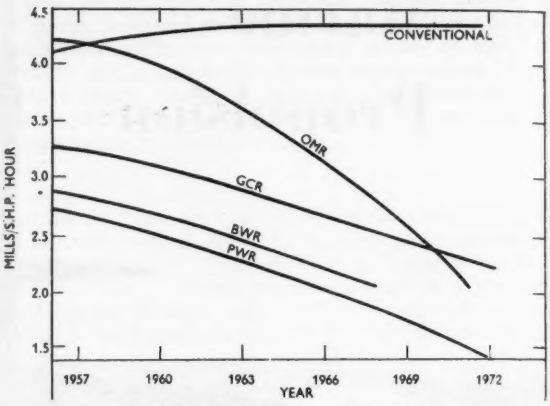
TABLE 1.—U.S.N. NUCLEAR PROPULSION PROJECTS

Vessels	Designation	Designer	Shipbuilder	Type	Operation
Submarines:					
Nautilus	SSN571	West	Elec. Boat	PWR (S2W)	1955
Seawolf	SSN575	GE	Elec. Boat	Sodium (S2G)	1956
Skate	SSN578	West	Elec. Boat	PWR (S3W)	1957
Swordfish	SSN579	West	Portsmouth	PWR (S4W)	1958
Sargo	SSN583	West	Mare Island	PWR (S3W)	1959
Skipjack	SSN585	West	Elec. Boat	PWR (S5W)	1959
Halibut	SS(G)N587	West	Mare Island	PWR (S3W)	1959
Seadragon	SSN584	West	Portsmouth	PWR (S4W)	—
Triton, 2 reactors	SS(R)N586	GE	Elec. Boat	PWR (S4G)	—
Scamp	SSN588	West	Mare Island	PWR (S5W)	—
Scorpion	SSN589	West	Elec. Boat	PWR (S5W)	—
Sculpin	SSN590	West	Ingalls	PWR (S5W)	—
Shark	SSN591	West	Newport News	PWR (S5W)	—
Snook	SSN592	West	Ingalls	PWR (S5W)	—
Thresher	SSN593	West	Portsmouth	PWR (S5W)	—
Permit	SS(G)N594	West	Mare Island	PWR (S5W)	—
Pollack	SS(G)N595	West	Not assigned	PWR (S5W)	—
Plunger	SS(G)N596	West	Not assigned	PWR (S5W)	—
Tullibee	SSN597	CE	Elec. Boat	PWR (S2C)	—
George Washington	SSB(N)598	West	Elec. Boat	PWR (S5W)	1959
Patrick Henry	SSB(N)599	West	Elec. Boat	PWR (S5W)	—
Theodore Roosevelt	SSB(N)600	West	Mare Island	PWR (S5W)	—
Robert E. Lee	SSB(N)601	West	Newport News	PWR (S5W)	—
Abraham Lincoln	SSB(N)602	West	Portsmouth	PWR (S5W)	—
—	SSN603	West	Not assigned	PWR (S5W)	—
—	SSN604	West	Not assigned	PWR (S5W)	—
—	SSN605	West	Not assigned	PWR (S5W)	—
—	SSN606	West	Not assigned	PWR (S5W)	—
—	SS(G)N607	West	Portsmouth	PWR (S5W)	—
—	SSB(N)608	West	Not assigned	PWR (S5W)	—
—	SSB(N)609	West	Not assigned	PWR (S5W)	—
—	SSB(N)610	West	Not assigned	PWR (S5W)	—
—	SSB(N)611	West	Not assigned	PWR (S5W)	—
Surface Ships:					
Guided Missile Cruiser Long Beach (2 reactors) (USN)	CG(N)160	West	Bethlehem	PWR (C1W)	—
Aircraft Carrier Enterprise (8 reactors) (USN)	CVA(N)65	West	Newport News	PWR (A2W)	—
Guided Missile Destroyer (2 reactors) (USN)	DLG(N)25	GE	Bethlehem	PWR (D2G)	—

engines or steam turbines. Although not a naval vessel, the philosophy governing the design and operation is similar to that found in the American naval programme.

Similarly in the U.S., the "Savannah," although a genuine merchant ship project, cannot even be regarded as a prototype. Prestige figured largely in the decision to build this ship and, in addition, in the U.S.A. it has been considered necessary to build a floating laboratory in order to assess fully the problems that will be encountered in the design and operation of nuclear-propelled merchantmen. Details of this project, together with estimates of its cost, appear on pages 197-199.

A great number of merchant ship feasibility studies have been conducted throughout the world, but in every case, the stumbling block is the poor economics shown in comparison with conventional propulsion systems. In general terms the capital cost of the propulsion system is some 20-30% higher for a nuclear ship than for a conventional ship and indeed, in present designs, the whole of the cost of the reactor represents an additional capital charge, as the actual propulsion machinery, together with heat exchangers (if necessary) and stand-by equipment are almost as expensive as the propulsion machinery and boilers of a steamship. Annual nuclear fuel costs must, therefore, be dramatically lower than those of conventional fuels but, in general terms, this is not possible at present due to the necessity of enrichment and the high cost of fabricating fuel elements. Only when very special operational conditions are considered, such as long haulage distances at high speed, can nuclear propulsion, for the time being, offer competitive rates. Economics based on a cost per ton are more favourable to nuclear propulsion than those based on a return on investment. Certainly for systems requiring less than 20,000 s.h.p. there is little immediate prospect of nuclear propulsion being economic. Twelve months ago there was considerable discussion over



Comparison of projected fuel costs for a 20,000-s.h.p., 40,000-ton tanker.

(*Gordon, J. J.*, 1958 *Nuclear Merchant Ship Symposium, Washington*)

the use of nuclear fuels in tankers of around 100,000 tons displacement, but the demand for ships of this size is at present small, and likely to diminish in the next few years.

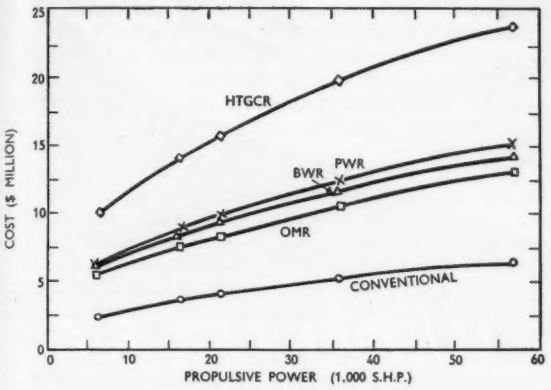
U.S. Merchant Ship Programme

The most comprehensive programme of nuclear merchant ship development has been established in the United States under the auspices of the Maritime Administration and the AEC. Four reactor systems are considered worthy of especial study; these are the pressurized water, the boiling water, the organic moderated and the high temperature gas-cooled. In a recent independent evaluation made by American Standard, it was concluded that the BWR and OMR were the two systems which could become competitive soonest. The BWR is regarded as the most attractive for nuclear ships in the immediate future, and the organic moderated reactor as the most attractive for the near future.

In the forefront of boiling water developments, the General Electric Co. have completed a number of studies. The company concludes that the direct cycle boiling water reactor can be safely installed in a merchant ship and will allow complete flexibility of operation. They quote possible fuel costs as 3 mills/s.h.p.h., which is equivalent to fuel oil costs of $2/barrel. The thermal efficiency of the cycle is calculated to be 27% and the weight of the system 1,850 tons, when designed to furnish 22,000 s.h.p. Operation of a 39,000-ton tanker powered by such a unit is calculated to cost some 10% more than a similar ship using a conventional propulsion system.

The organic moderated system has been studied by Atomics International who, on the basis of OMRE results, conclude that the system offers the lowest capital charge due largely to the employment of mild steel in the primary circuit. Limiting features of the design are the break-up of the organic moderator and the relatively poor steam conditions that must be accepted if this break-up is to be minimized. The OMR is not yet a fully developed system and improvements in fuel costs and in the radiation resistance of the organic, could make an appreciable difference to the economics.

The pressurized water reactor which has been developed by Westinghouse for naval craft and by Babcock and Wilcox for the "Savannah" is the most fully developed plant for marine propulsion at the present time. There is considerable room for improvement in fuel element fabrication costs, but even so, only the most optimistic evaluations indicate that this system is ever likely to be competitive with conventional propulsion systems.



Comparison of total construction costs of propulsion plants for an ore carrier.
(*Conklin, D. L.*, 1958 *Nuclear Merchant Ship Symposium*)

In the long term the high temperature gas-cooled reactor is regarded in many quarters as the most optimistic, although the design problems to be overcome are formidable. The General Atomic Division of General Dynamics is developing for the Maritime Commission and the AEC the Maritime Gas-cooled Reactor, comprising a high temperature gas-cooled system coupled directly with a closed-cycle gas turbine propulsion system. Research is continuing into the choice of both working fluid and moderator. For the coolant, carbon dioxide and helium are being investigated, and for the moderator, graphite, beryllium oxide, light and heavy water and zirconium hydride are all being considered. The high temperature properties of graphite make this material the most attractive, but cladding will be necessary if carbon dioxide is chosen as the coolant. The high atomic number also implies a larger core and a greater capital cost for the plant. Beryllium oxide offers a more compact core structure and better neutron economy but it is expensive, brittle and sensitive to thermal shock. Hydrogen moderation produces the smallest core; thermal insulation of water introduces a number of engineering complexities and neutron economy is not good. Zirconium hydride, adopted in the company's research reactor, has encouraging properties. It can operate at high temperatures with only a small dissociation pressure of hydrogen. Diffusion of hydrogen through the material and through any cladding and the tendency of hydrogen to migrate, poses formidable problems. On the fuel side, the most promising approach is to mix the fuel homogeneously with the moderator and a number of solid homogeneous uranium graphite mixtures are being tested.

A novel propulsion system suggested at the Washington Nuclear Merchant Ship Symposium uses a gas-cooled reactor driving a reciprocating engine. The gas is compressed and passed to the reactor where it is heated, the hot gas then returns to the cylinder which is expanded to do work; at the end of the expansion stroke the piston uncovers ports which permit loop scavenging in the cylinder by a low pressure gas system, which includes a cooler and a blower to complete the thermodynamic cycle.

A recent proposal for a gas-cooled reactor similar to the AGR that is with a graphite moderator and an output temperature of around 950°F, has recently been proposed by a special industrial group comprised of Ford Instrument, Division of Sperry Rand Corporation, Maryland Shipbuilding and Drydock Co. and the Isbrandtsen Co. Plans call for the erection, pretesting and installation of the reactor, in the cargo section of a 32,800-ton tanker launched in July last year, the system having been pretested on land in a mock-up of the cargo section. Government support for this system is, however, essential before it can go ahead.

World Projects

In *Denmark*, a consortium of Danish industrial concerns which is currently studying the design of a 160-MW gas-cooled graphite-moderated power station has announced that it is now working on plans for a 65,000-ton tanker.

In *France*, two groups Indatom and France-Atome have both submitted feasibility studies to the Commissariat. Indatom have considered gas-cooling with both graphite and heavy water moderation and France-Atome both BWR and PWR designs. The evaluation was based on a 40,000-ton tanker of 20,000 s.h.p.

In *Germany* it was announced at the beginning of this year that Gesellschaft fuer Kernenergie in Schiffbau und Schiffahrt had signed an agreement with Interatom (comprising Demag and Atomics International) for an organic moderated reactor ship study. The initial contract is based on a 2½-year development period and concerns a 10,000 s.h.p. unit, but no decision will be taken on the building of a prototype yet.

Deutsche Werfr. A.G. is also reported to be studying a 44,000-ton tanker design believed to be incorporating a PWR.

In *Holland*, a study group has been set up under the auspices of Reactor Centrum Nederland (a body comprising representatives of Government, Industry and Academic Institutions) by a group of shipowning and shipbuilding companies. Results of the work of this group have not yet been published.

In *Italy*, Fiat announced in the middle of last year that,

Projets de Propulsion Nucléaire.

Autres que le " Savannah " et le programme de la Marine des Etats-Unis, et le " Lénine " en Russie, un nombre de dessins de navires nucléaires sont à l'étude. Aux Etats-Unis, quatre systèmes de réacteurs sont considérés comme prometteurs, le Réacteur à Eau Bouillante, le Réacteur à Eau Pressurisée, le Réacteur Modéré Organique et le Réacteur à Haute Température refroidi au gaz. L'Allemagne, la Hollande, l'Italie, la France, la Norvège, la Suède et le Japon ont tous des programmes de construction de navires à l'étude. Au Royaume-Uni, deux projets de sous-marins de la Royal Navy sont à l'étude, et tant dans les sphères gouvernementales que commerciales il se dépense une somme d'efforts sur les développements marins civils.

Kernkraft-Antriebs-Projekte.

Abgesehen von der im Bau befindlichen " Savannah " und dem Programm der amerikanischen Marine, weiter dem " Lenin " in Russland, laufen Untersuchungen über eine Anzahl von Entwürfen kernkraftgetriebener Schiffe. In den Vereinigten Staaten glaubt man, dass vier Reaktor-Systeme vielversprechend sind, nämlich der Siedewasser-Reaktor, der Presswasser-Reaktor, der Reaktor mit organischem Moderator und der mit hoher Temperatur arbeitende gasgekühlte Reaktor. Deutschland, Holland, Italien, Frankreich, Norwegen, Schweden und Japan, alle beschäftigen sich mit dem Studium des Schiffsantriebs. In England arbeitet man an Projekten für zwei Unterseeboote der Marine, und Handelskreise wie Regierung wenden viel Arbeit an die Entwicklung von Systemen für die Handelsmarine.

Proyectos de Propulsión Nuclear.

Aparte de la N.N. " Savannah " y del programa naval de los E.E.U.U. y la " Lenin " en Rusia, se están investigando diversos otros diseños de naves nucleares. En los E.E.U.U. hay cuatro sistemas de reactor que se consideran como prometedores, el Reactor de Agua Hirviente, el Reactor de Agua Presurizada, el reactor orgánicamente moderado y el reactor de alta temperatura enfriado por gas. Alemania, Holanda, Italia, Francia, Noruega, Suecia y el Japón todos tienen estudios en progreso de naves nucleares. En el Reino Unido hay en estudio dos proyectos navales de submarinos, y tanto por el lado comercial como por el lado gubernativo se están haciendo esfuerzos en la evolución de una marina mercante nuclear.

An experimental core assembly for the N.S. "Savannah"

with Ansaldo, they were to study the construction of a 68,000-ton tanker, powered by a 74 MW(t) PWR giving 30,000 s.h.p. The year previously Fiat concluded a manufacturing and licensing agreement with Westinghouse of America.

In *Japan*, four groups are known to be interested in nuclear propulsion, Mitsubishi Heavy Industries, Kawasaki Heavy Industries, Harima Dockyard and Tokyo University and a group comprising Ishikawajima Shipyard, Hitachi Shipyard, Mitsui Shipyard, Japan Steel Tube Co. and the Maritime Safety Agency. Two papers were submitted to the Geneva Conference, the first (1320) concerning a 48,200-ton submarine tanker with a speed of 22 knots, powered by a 180 MW PWR, and the second (1319) an immigrant ship of 20,100 tons with a speed of 23.5 knots designed to carry 2,500 people and 8,000 tons of cargo also powered by a PWR. In this second study it was concluded that, although such a project could be profitable, it could still not compare with conventional propulsion methods.

In *Norway*, the Joint Establishment for Nuclear Energy Research at Kjeller, launched at the end of last year a £75,000 research project to study nuclear propulsion methods, following a contract placed by Rederiatom, a group of Norwegian shipowners.

In *Sweden*, Götaverken Shipyard in Gothenburg has prepared plans for a 65,000-ton tanker with a BWR propulsion unit generating 32,000 s.h.p.

United Kingdom

In the U.K., a number of studies have been undertaken by industrial organizations. Babcock and Wilcox as a result of their agreement with their U.S. namesakes have a considerable interest in the "Savannah" project and have independent investigations in hand. This company in association with Cammell Laird has also conducted studies on gas-cooled systems initially of the Calder type, but lately with greater attention on the advanced gas-cooled system.

Mitchell Engineering who with AMF Atomics and GNEC are developing land-based pressurized boiling water reactors have been conducting experiments in co-operation with Saunders-Roe on the hull design of a nuclear propelled submarine tanker. As a result of this work, Mitchells have now concluded a development agreement with Fairfield Shipbuilding and Engineering.

Hawker Siddeley announced last year that they were co-operating with John Brown in studying marine propulsion problems but the detailed activities of this group have not yet been published.

Gel Tankers of London at the beginning of last year announced that they had reached agreement with Maierform S.A. of Geneva for joint preliminary investigation into the construction of a 68,000-ton tanker.

Rolls-Royce and Vickers are both, of course, heavily engaged on the naval programme, but it is presumed that their interests are not confined solely to military applications.

The U.K. AEA has conducted studies both on the natural uranium gas-cooled graphite-moderated reactor system and on the AGR, and the results of its AGR studies are expected shortly. The British Shipbuilding Research Association has had a team at Harwell for some years concentrating on more fundamental problems, particularly those regarding fuel cycles and the potentials of plutonium burning. In co-operation with the Admiralty and the AEA the Yarrow Admiralty Research Department have also been making intensive investigations into competitive systems. Pametrada has also had a group working in this field.

On the safety side, the insurance companies and Lloyd's have been preparing themselves for the eventual adoption of nuclear-propulsion methods and the Ministry of Transport has set up a special committee to evaluate basic safety requirements and probable special requirements for manpower and dock facilities.

The Government is maintaining its contact with nuclear ship developments through the Galbraith Committee. Comprised predominantly of Admiralty and AEA representatives the Committee also includes members from the Ministry of Transport, the Ministry of Power, the General Council of British Shipping, B.S.R.A. and Lloyd's. It is expected that a comprehensive report on the present state of technological developments set against a background of shipping requirements will be submitted within the next few weeks—probably in May. It is to be hoped that the contents will be made public as soon as is practicable.

N.S. "Savannah," see opposite

La quille du N.N. "Savannah" fut jetée le 22 Mai 1958 et on prévoit que le navire commencera ses essais de mise en service au début de l'année prochaine. Conçu avec une longueur totale de 182 mètres et une largeur de 23,8 mètres, un déplacement de 21.800 tonnes pour le transport d'une cargaison de 10.000 tonnes et de 60 passagers à une vitesse normale de 21 noeuds et mû par un Groupe Réacteur à Eau Pressurisée de 70 MW (t) développant une puissance sur l'arbre de 22.000 chevaux, le Savannah sera le premier navire pour passagers et cargaison à être propulsé par l'énergie nucléaire. Des détails du réacteur et des systèmes de propulsion sont donnés dans le mémoire.

Die Kiellegung von N.S. "Savannah" fand am 22. Mai 1958 statt, und die Uebernahme-Probefahrten des Schiffes sollen termingemäss Anfang nächsten Jahres beginnen. Das Schiff hat eine Länge über alles von 182 m, eine grösste Breite von 23,8 m, eine Wasserverdrängung von 21 800 t und soll eine Ladung von 10 000 t und 60 Passagieren mit einer Durchschnittsgeschwindigkeit von 21 Knoten befördern. Die Maschinenanlage besteht aus einem Druckwasser Reaktor von 70 MW (t) und einer Maschine, deren Leistung an der Welle 22 000 PS beträgt. Die "Savannah" wird das erste kombinierte Passagier- und Frachtschiff mit Kernkraft-Antrieb sein. Einzelheiten des Reaktors und des Antriebsystems werden dargestellt.

La quilla de la N.N. "Savannah" fué puesta el día 22 de mayo de 1958, y la nave está programada a comenzar sus pruebas de puesta en servicio en los primeros dias del año 1960. Diseñada con una eslora total de 182 metros y manga de 23,8 metros, un de 1958, y la nave está programada a comenzar sus pruebas de desplazamiento de 21.800 toneladas para transportar una carga de 10.000 toneladas y 60 pasajeros a un andar normal de 21 nudos y propulsada por una unidad de reactor de agua presurizada de 70 MW (t), desarrollando 22.000 H.P. al freno, la N.N. "Savannah" será la primera nave nucleopropulsa de cargo y pasajeros. Se ofrecen detalles de los sistemas de reactor y propulsión.

N.S. SAVANNAH

THE keel for the " Savannah," the first nuclear-propelled merchant ship was laid on May 22, 1958, in the yards of the New York Shipbuilding Co. at Camden, New Jersey. In length 596 ft, and 78 ft in the beam with a displacement of 22,000 tons, the " Savannah " will carry a cargo of some 10,000 tons as well as 60 passengers at a normal speed of 21 knots. She will be powered by a pressurized water reactor developed and fabricated by Babcock and Wilcox, who joined the project in October, 1956. The Company has contracted to maintain the development and construction schedule of 39 months, which would allow the vessel to be commissioned early in 1960; the DeLaval Steam Turbine Co. has been engaged as primary subcontractor for the manufacture of major components.

A prime consideration in the design of the plant has been a long cruising range, which is expected to be a minimum of 350,000 miles although a figure of 500,000 miles may be achieved with the first core. The major portion of the reactor system, including the reactor itself, the primary coolant loops, the pressurizer, steam generators, primary circulating pumps and most of the ancillary systems and air-conditioning systems will be housed in a cylindrical containment vessel, 35 ft in diameter and 50.5 ft long, lying fore and aft in the centre of a 67½ ft compartment located almost exactly amidships (Fig. 1). The machinery space is set immediately aft of this.

The reactor itself is a pressurized water reactor with a maximum rating of 74 MW operating at 1,750 p.s.i.a. and fuelled with stainless steel clad uranium oxide fuel elements, with an initial enrichment of 4.7%. The primary coolant makes three passes through the core section. The first is upwards between the vessel and the inner thermal shield, the second is downwards through the 16 outer fuel elements, the final pass being upwards through the central core region. Steam is produced in two U-shell U-tube boilers at a pressure of 455 p.s.i.a. on full load. Steam pressure at the turbines is a function of the load taken and rises to 730 p.s.i. at zero power. The mean temperature of the coolant in the reactor is maintained constant, partly by the use of control rods and partly through the large negative temperature coefficient.

Principal Design Features

Length	596 ft
Beam	78 ft
Displacement	21,800 tons
Speed	21 knots
Power (normal)	20,000 s.h.p.
Power (max.)	22,000 s.h.p.
Range	500,000 miles
Reactor type	PWR
Reactor rating (design)	74 MW
Reactor rating (normal operating)	63 5 MW
Operating pressure	1,750 p.s.i.a.
Bulk coolant outlet temperature	521.3°F
Fuel	boronated s.s. clad UO_2
Enrichment	4.7%
Steam pressure at T.S.V. (22,000 s.h.p.)	450 p.s.i.a.
Feedwater temperature	347°F
Total steam production	242,200 lb/h

Reactor Core

Designed for a minimum operational period of 600 days at an output of 68 MW, involving a total burn-up of about 48 kg U^{235}, the core of the " Savannah " reactor comprises a right circular cylinder, 62 in. diameter by 66 in. high. It is made up of 32 fuel elements each 8.5 in. square and 85 in. long, including end-fittings. Secured in an " egg-crate " type lattice (which, should metallurgical behaviour permit, is a permanent fixture) in a square array, on a 9.7 in. pitch, each element comprises four rectangular fuel bundles, each containing 41 fuel rods 0.45 in. o.d. maintained at a 0.663 in. pitch by stainless steel ferrules brazed approximately every 8 in. (Fig. 2). The fuel rods contain uranium oxide pellets of 0.4245 in. diameter, sintered to 91% of theoretical density, canned in boronated type 304 stainless steel tube of all thickness 0.035 in. An atmosphere of helium is maintained in the fuel rods, introduced during the end-plug welding process. The egg-crate lattice structure is provided with walls of stainless steel, 0.109 in. in the outer region and 0.94 in. in the inner region.

The lattice is held between the lower and upper grid plates, the first of which is carried by the core support shield, the rigidity of the assembly being maintained by hold-down springs which transmit the hold-down thrust from the vessel wall through 18 equally-spaced struts to the upper grid plate. The complete core structure including the shields and the plenum chambers is carried by

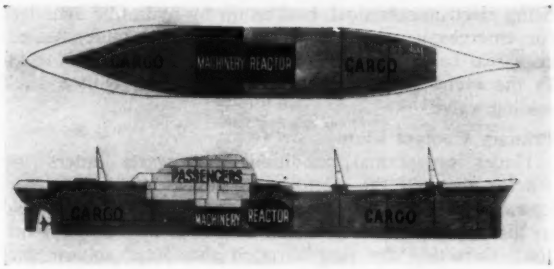


Fig. 1.—Section and plan at D deck level of the N.S. " Savannah."

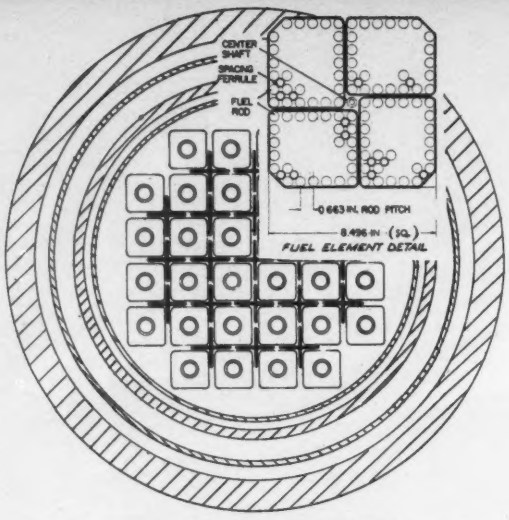


Fig. 2.—Cross-section of pressure vessel and core showing detail of fuel element.

the core support skirt, which is welded to the vessel wall just below the outlet nozzles. The core is, in fact, surrounded by three shields, the inner thermal shield, the core support shield and the fixed outer shield. The structure is designed to withstand the maximum accelerations resulting from pitching and rolling, and even to accommodate complete capsize of the vessel.

Pressure Vessel

The pressure vessel for the reactor (Fig. 3) 26.5 ft high, 98 in. i.d. is fabricated from 6 in. carbon steel plate, clad on the inside with type 304 stainless steel, and is designed for a pressure of 2,000 p.s.i. at a temperature of 650°F. The head which carries the control rod drives is held down by 48 5-in. studs, sealing being effected by a double-gasket and a seal weld between the flanges. The effective closure area is 90 in. diameter and allows removal of all items in the core which are likely to need maintenance. The vessel is mounted vertically within the containment vessel with the two heat exchangers on each side.

Controls

In the cold clean condition the core should have an excess reactivity of approximately 15.5% $\Delta k/k$. Of this 6.5% represents the negative temperature coefficient from 68°F to 508°F, 2.8% xenon poisoning, 4.2% burn-up and a manufacturing tolerance of 2.0% has been allowed.

Control rod design has been based on an overall reactivity control of 18.5% made up of 15% in the control rods themselves and 3.5% as burnable poison. Reactivity override for xenon-135 is only 0.15% due to the low thermal neutron flux expected, viz., 8×10^{12} n/cm², sec.

Twenty-one cruciform control rods are provided, each 8 in. long, made up of $\frac{1}{16}$ in. boronated stainless steel plate, sandwiched between two $\frac{5}{32}$ in. ordinary stainless steel plates. The rods are supported from the reactor head, but can be disconnected for removal of the head, the drives being electromechanical, backed up by hydraulic cylinders for emergency operation. Drive lines are buffer sealed, each seal being charged with purified water at 1,800 p.s.i. In the event of failure, the seal is isolated with a back seating valve.

Primary Coolant Flow

Under operational conditions, the water enters the reactor through the bottom nozzles at 494.7°F, passes upwards between the vessel and the inner thermal shield to the upper grid plate, which acts as a turn-down manifold, deflecting the flow through the outer sixteen fuel elements, into the lower plenum chamber. A minimum of 85% then passes upwards into the sixteen inner guide tubes and thence to the central elements, whilst approximately

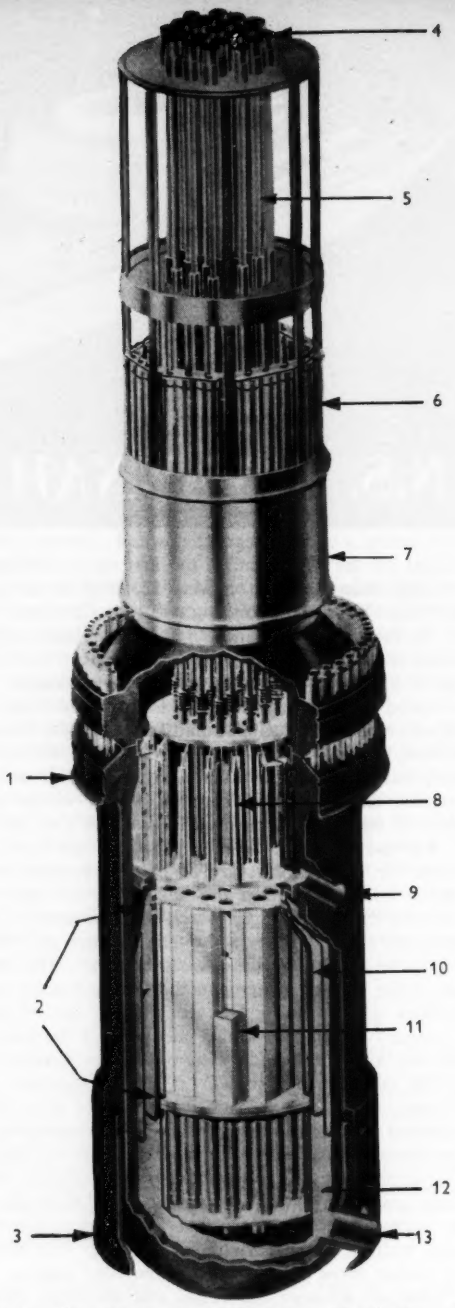


Fig. 3.—The reactor vessel; (1) flange (2) effective core height (3) support skirt (4) motor drives (5) hydraulic cylinders (6) lead-screw (7) gland seal closure (8) control rod (9) water outlet (10) thermal shields (11) fuel elements (12) flow baffle (13) water inlet.

5% is used for control rod coolant, the remaining 10% being used for reflector coolant and to take account of leakage into other regions of the reactor. The various streams mix in the upper plenum chamber and turn down to flow out through the exit nozzles.

Although this multi-pass system would appear to offer dangers from the point of view of flow reversal under fault conditions with resultant burn-out, analysis indicates that even with a single pump running at half speed only, and a factor of two in power density arising between two fuel elements in the second pass, flow reversal should not take place. With the reactor shut down, decay heat flux is not sufficiently great for elements to melt, even if flow reversal should occur.

A coolant flow of 8,000,000 lb/h is maintained through the two heat transfer loops by two pairs of canned-rotor circulating pumps, each provided with half and full speed windings. The rating of the pumps is 250 kW delivering 5,000 gal/min at 495°F with a head of 70 p.s.i. Main primary piping is in 12$\frac{3}{16}$ in. i.d. and branch piping in 8$\frac{3}{16}$ in. i.d. type 304 stainless steel fabricated from hollow forgings, with a design pressure of 2,000 p.s.i. Two isolating gate valves are provided in each loop. The system is pressurized to 1,750 p.s.i. by an electrically heated pressurizer in which steam space is maintained in equilibrium with water, either by heating or spray cooling. Temperature rise through the reactor at full power is 24.8°F.

For purification purposes, a bleed of 20 gal/min is taken from the system; the temperature and pressure of the water are reduced to 110°F and 50 p.s.i.g. respectively, which is then passed to three de-mineralizers and filters to the buffer seal search tank. Normally, return of this purified water is through the buffer seals on the control rod drives.

A minimum concentration of 20 cc/litre of dissolved hydrogen is maintained in the primary loop to scavenge radiolytic oxygen.

The two boilers are of U-shell U-tube type, approximately 20 ft long, each being fitted with 800 $\frac{1}{2}$-in. stainless steel tubes. Steam drums are mounted overhead, these being fitted with cyclone separators and scrubbers. The primary coolant is fed to the tube side of the generators at a temperature of 520.4°F. The secondary side has been designed for a pressure of 800 p.s.i., steam being fed to the turbines through 8-in. piping.

The primary shield for the reactor is an annular layer of water, 33 in. thick, contained in a carbon steel tank of 1-in. wall thickness. The tank is lined with lead on the outside to a thickness of 1-3 in. Dose-rate in the boiler compartment will be less than 1 r/h soon after shut-down allowing access for maintenance.

The primary system is contained in a vessel designed to withstand a pressure of 185 p.s.i., 51 ft long and 35 ft in diameter. It is fabricated from steel plate of 1$\frac{1}{4}$ in. thickness increasing to 4 in. at the main access port. Over the upper half, including access domes, additional shielding comprising 6 in. polythene and 6 in. lead is provided and surrounding the whole is 3 ft 6 in. of concrete largely ordinary, but including some barytes in special sections. Outside the shielding, the dose-rate will be less than 5 r/year.

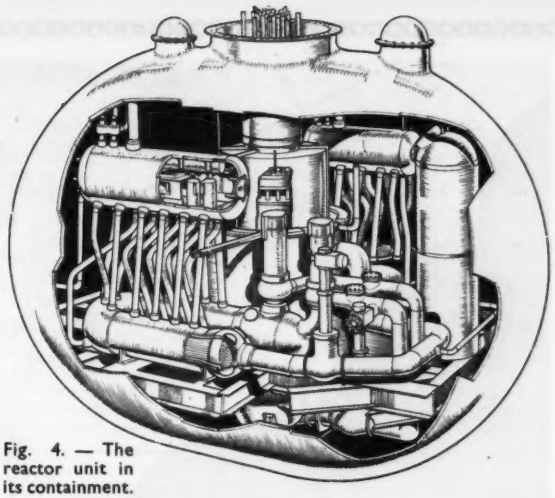


Fig. 4. — The reactor unit in its containment.

Emergency power will be provided by two 750 kW diesel generators (which come into operation automatically on loss of reactor power), a 300 kW diesel generator, maintaining a battery bank to provide emergency power for instrumentation and a 7,500 lb/h, 150 p.s.i. package boiler for emergency steam. A 750 h.p. emergency take-over motor, driven from the diesel generators, can be coupled to the double reduction gear on the propeller drive.

Preliminary figures for the "Savannah" indicate that the reactor and power plant will cost in the region of 14\frac{1}{2}$ million, while the shielding and containment alone will cost around $1.5 million. A conventional propulsion system of the same power could be expected to cost in the region of $6 million. Fuel costs for the first core will also be high, the aggregate figure amounting to about 8.0 mills/s.h.p.h. This includes 2.61 mills for the U^{235} burnt, a credit for plutonium of 1.63 mills and a reprocessing cost of 0.59 mills.

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"Safeguards in the American Nuclear Merchant Ship Programme," Geneva Conference, P/1023,

THERMAL AND HYDRAULIC

Reactor design power	74 MW
Reactor maximum operating power	69 MW
Reactor normal operating power	63.5 MW
Design pressure	2,000 p.s.i.a.
Operating pressure	1,750 p.s.i.a.
Total reactor flow rate	8.0×10^6 lb/h
Velocity (average, second pass)	9.29 ft/sec
Velocity (average, third pass)	8.40 ft/sec
% leakage flow (second pass)	5%
% leakage flow (third pass)	10%
% total leakage flow	15%
Number of passes within reactor vessel	3
Bulk coolant inlet temp.*	494.7°F
Bulk coolant outlet temp.*	521.3°F
Average coolant temp. (second pass)*	499°F
Average coolant temp. (third pass)*	512°F
Core average coolant temp.*	508°F
Maximum element surface temp.	610°F
Maximum fuel temp.	3,660°F

* At design power.

STEAM CONSUMPTION

Main turbines	186,610 lb/h
Feed pump turbine	24,750 lb/h
Turbogenerators	28,280 lb/h
Low pressure steam generator	705 lb/h
Air ejectors, sep'rs, losses	1,855 lb/h
Total generation required	242,200 lb/h

HEAT TRANSPORT

Steam generators	62.8 MW
Purification system	1.2 MW
Primary pumps	-0.7 MW
Heat losses	0.2 MW
Reactor	63.5 MW
Primary loop pressure	1,750 p.s.i.a.
Primary loop pressure drop	69.5 p.s.i.a.
Primary loop flow	8,000,000 lb/h
Primary loop temp. rise	22.8°F
Primary loop mean temp.	508°F
Blowdown	2,400 lb/h

CORE DIMENSIONS

Core overall length	90.24 in.
Active fuel length	66 in.
Equivalent core diameter	62.06 in.

FUEL ELEMENTS

Fuel	UO_2
Cladding	Boron stainless steel
Ferrules, can, straps	Stainless steel
Springs	Inconel-X
Fuel pellet diameter	0.4245 in. (nominal)
Cladding outside diameter	0.500 in. (nominal)
Cladding thickness	0.035 in. (nominal)
Fuel rod spacing (square lattice)	0.663 in. (nominal)
Fuel rods per element	164
Ferrule outside diameter	0.4375 in. (nominal)
Ferrule inside diameter	0.3975 in. (nominal)
Length of ferrule	1.0 in.
Fuel elements in core	32
Fuel element can thickness /second pass)	0.109 in.
(third pass)	0.094 in.
Heat transfer area	3778 ft²

NUCLEAR DATA

Metal/H_2O ratio	0.76
Volume fractions	
Water	0.5676
Control rods	0.0397
Helium gap	0.0064
Fuel	0.2455
Stainless steel	0.1408

Typical Inventory and Fuel Burn-up Data for 52,000 MWD Core Life

Initial enrichment (wt %)	4.7%
Initial U-235 loading	331.4 kg
Initial U-238 loading	6,734 kg
Average burn-up	7,360 MWd/t
Final enrichment (wt %)	3.9%
Final U-235 loading	272.9 kg
U-235 consumed	58.4 kg
Final Pu-239 loading	17.4 kg
Final total Pu loading	19.6 kg
Percent metal atom burn-up	1.2%
Average thermal neutron flux	7.5×10^{13}

THE GARIGLIANO NUCLEAR POWER STATION

By Professore-Ingegnere **C. MATTEINI**
(*President, Societa Elettronucleare Nazionale*)

The "ENSI-Project" dealt with by the Societa Elettronucleare Nazionale (SENN) has now reached the stage where a decision has been made in favour of the boiling-water type of reactor. The 150 MW station will be sited on the West coast of the country near the mouth of the River Garigliano and will be built by the International General Electric Co. The information presented includes data on cost analysis.

HISTORY OF THE PROJECT

THE first nuclear power station of the boiling-water type in Italy, will be built by International General Electric Co. for SENN (Societa Elettronucleare Nazionale) and have a net electrical capacity of 150,000 kW. The plant will be located near the mouth of the Garigliano River from which it derives its name, approximately mid-way between Naples and Rome. Construction will start next spring and operation is scheduled to begin late 1962 or early 1963.

The project actually originated more than a year ago, when a number of electric power undertakings and manufacturing companies joined in the establishment of the Societa Elettronucleare Nazionale with the object of building a large nuclear power station in southern Italy. Most of the utilities and manufacturers belong to the state-owned Istituto Riconstruzione Industriale (I.R.I.). It was then recognized that Italy was bound to become one of the first countries in the world where nuclear power would be competitive with conventional sources of energy, and that the only way to obtain experience in the field was to actually build and operate a large nuclear station.

The initiative very soon received the support of both the International Bank for Reconstruction and Development (I.B.R.D.) and the Italian Government. The latter acted through C.N.R.N., Comitato Nazionale Ricerche Nucleari. In conjunction with these two agencies, SENN prepared a rather extensive programme of work, which was given the name "ENSI-Project," in order to invite all the more important nuclear manufacturing companies in the world to prepare bids for the project, and to organize a close evaluation of the bids.

As a result of this programme, on October 30, 1957, a detailed "Invitation to Bid" for a 130-150 MW nuclear power plant was sent to 22 manufacturing companies in Belgium, Canada, France, Great Britain and the United States.

The following nine groups accepted the invitation and submitted their proposals by April 30, 1958:

United States

(1) H. K. Ferguson and Babcock and Wilcox, Atomic Energy Division.

(2) Kaiser Engineers and Westinghouse Electric International Co.

(3) International General Electric Co. and Ebasco Services, Inc.

(4) Atomics International and Bechtel Co.

Great Britain

(5) Mitchell Engineering, Ltd., and A.M.F. Atomics, Inc. and General Nuclear Engineering Corp.

(6) A.E.I.-John Thompson Nuclear Energy Co., Ltd.

(7) English Electric Co., Ltd., and Babcock and Wilcox, Ltd.

(8) General Electric Co., Ltd., and Simon-Carves, Ltd.

France

(9) France-Atome.

Bidders Nos. 1 and 2 offered reactors of the pressurized water type; bidders Nos. 3 and 5 proposed boiling-water reactors; the plant proposed by bidder No. 4 used an organic-moderated reactor; bidders Nos. 6, 7, 8 and 9 offered gas-cooled, graphite-moderated reactors.

The tenders received were examined and evaluated by the following:

Argonne National Laboratory, on behalf of U.S.AEC—liquid-cooled reactors;

U.K.AEA—gas-cooled reactors;

An International panel composed of well-known nuclear experts, and

British and American consultants, jointly with the staff of SENN and C.N.R.N.

At the end of September, 1958, on the basis of the results obtained from the evaluation programme, the decision was made by SENN to choose the bid submitted by International General Electric Co. as being the one most suited to SENN's particular needs. The main reasons for this choice were as follows:

(1) The capital cost per kWh sent out by the I.G.E. plant proved to be the lowest; Fig. 1 shows, for the various bids, the total cost of generated energy as a function of fixed charges for a 70% load factor;

(2) nothing fundamentally objectionable on technical or any other ground was found in the I.G.E. offer, taking into consideration the present state of nuclear technology and its many unknown factors;

(3) the I.G.E. design possessed a high degree of flexibility in operation, a very attractive feature in relation to the requirements of the Italian electricity grid;

(4) the I.G.E. design offered the possibility of future improvements, both from the performance and the economical standpoint.

It is estimated that about 60-70% of the total plant will be manufactured and built in Italy, the main item being the turbogenerator which will be built by the Ansaldo Co. of Genoa. When completed, the plant will be capable of supplying about one thousand million kilowatt hours per year, contributing substantially to the availability of power in central and southern Italy. SENN company is determined vigorously to follow through the construction of the plant and to adhere to the schedule as laid down initially.

SELECTION OF THE SITE

A number of favourable conditions led to the choice of a site, in the province of Caserta, on the south bank of the Garigliano River. The area is sparsely inhabited, a feature not very common in Italy. The Garigliano River has a permanent flow sufficient for condenser cooling requirements and the water temperature is sufficiently low all the year round. Meteorological investigations have given favourable results. The seaside location is advantageous for many reasons particularly because the prevailing winds are off-shore. No earthquake has ever been recorded on the site.

DESCRIPTION OF THE PLANT

General Operational Data

The Garigliano station is a boiling water, dual cycle, forced circulation reactor system. The reactor, all steam generating equipment, reactor system auxiliaries, fuel handling and storage facilities are enclosed in a containment sphere. The turbine building contains the turbine-generator and its auxiliaries, the condenser, condensate and feedwater system equipment, and station auxiliaries.

Attached to the turbine building are the machine shop and the waste treatment building.

Some of the more important data relating to the performance of the plant are given in the table below.

Installed capacity	160,000 kW
Net electrical output	150,000 kW
Reactor power	507,800 kW
Reactor operational pressure	1,015 p.s.i.a.
Net plant heat rate	11,533 B.t.u./kWh
Primary steam flow	1,543,540 lb/h
Primary steam drum pressure	990 p.s.i.a.
Secondary steam flow	479,400 lb/h
Secondary steam generator pressure	500 p.s.i.a.
Feedwater flow	2,033,040 lb/h
Feedwater temperature	375 °F
Turbine back pressure	1.25 in. Hg abs

More performance figures are shown in the (simplified) flow diagram, see Fig. 2.

General Functional Arrangement

In the dual cycle boiling-water reactor (Fig. 2), primary steam is produced in the reactor vessel and is carried as a steam-water mixture from the reactor to the primary steam drum, where the steam is separated from the water for use in the turbine. A minimum outlet quality of 99.9% is required for the steam. From the steam drum the reactor water is pumped by the recirculating pumps through the tube side of the secondary steam generators, and flows back to the reactor. In the secondary steam generators, steam is produced at a lower pressure and flows to the turbine through the secondary inlet. The primary and secondary steam pass through a conventional turbine with a condenser, a full-flow condensate demineralizer, feed pumps and extraction feedwater heaters. The feedwater is returned to the primary steam drum and to the secondary steam generators.

In the dual cycle the pressure in the reactor is held constant by the primary control valves. Good control is achieved over a 30% range by the turbine governor system, without repositioning control rods. In case of an increased load demand on the turbogenerator, more secondary steam is admitted to the turbine by the secondary steam inlet valves. This, in turn, lowers the temperature of the water returning to the reactor; such increased subcooling reduces the amount of steam bubbles within the core and the reactor output rises to meet the load demand. The reverse takes place in case of a load reduction.

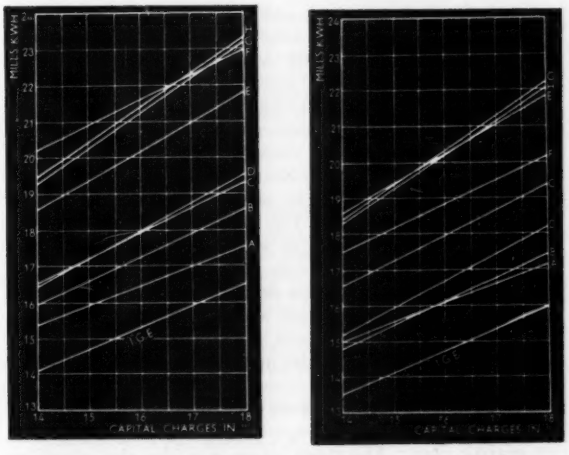


Fig. 1.—Total cost of generated kWh versus capital fixed charges for a 70% load factor. (a) (left)—Guaranteed output and burn-up. (b) (right)—Design output and burn-up.

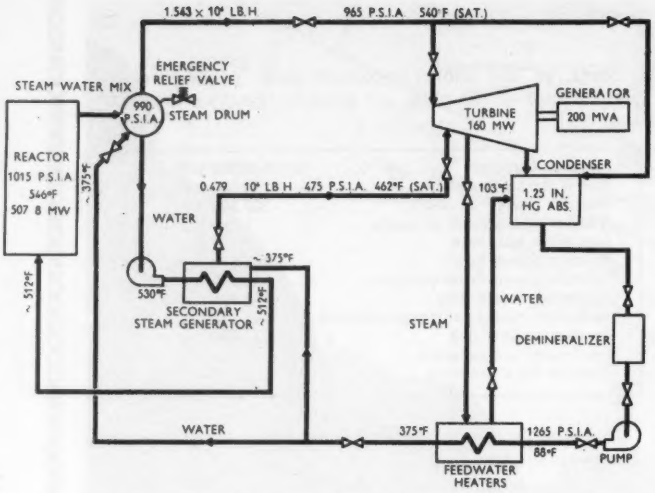


Fig. 2.—Simplified flow diagram of the 150 MW boiling-water reactor.

Pressure Vessel and Primary Loops

Figs. 3 and 4 show the general arrangement of the major reactor components within the containment sphere. There are two main circulating loops with two secondary steam generators and two recirculating pumps; the primary steam drum and the inter-connecting pipes are clearly shown. The control rods are inserted from the bottom of the pressure vessel, where room is provided for the control rod drive hydraulic mechanism and other reactor auxiliaries. Above the steam drum the emergency condenser is located discharging through the top of the sphere. Fig. 4 shows also how the fuel handling is performed by hand, guided by direct visual observation, following the system adopted in other water-cooled reactors.

The pressure vessel is cylindrical with hemispherical top and bottom ends. It is a forged and welded structure made from carbon steel and clad with type 304 stainless steel. Total thickness of the vessel wall is $5\frac{1}{8}$ in., inside diameter is 136 in. and the total height is approximately 35 ft. The vessel is designed for 1,250 p.s.i.g. pressure and the total weight is 215 tons, including the top cover. The coolant water enters the bottom of the vessel through two 24-in. nozzles and passes up through the core where bulk boiling produces steam. The steam-water mixture leaves the vessel through six 18-in. outlet nozzles and is passed to the primary steam drum.

Concrete shielding, of an approximate density of 140-150 lb/ft^3, is provided for the reactor pressure vessel as well as for all the primary loop and its components. Some shielding is also provided inside the turbine building as the turbine is radioactive during operation. Limited access is allowed to the containment sphere during operation to permit some operating and maintenance functions.

All components of the primary loop in contact with the primary fluid are either clad with stainless steel or made from solid stainless steel. The reactor pressure vessel, the primary steam drum, and the water box of the secondary steam generator are clad with stainless steel. The forced circulation piping, risers and downcomers, heat exchanger tubes and circulating pumps are of solid stainless steel. Structural portions of the core and its support, the internal thermal shield and other parts in the vicinity of the core are also of stainless steel.

The primary steam drum serves the purpose of separating the steam from the steam-water mixture generated in the reactor core. The steam drum provides also adequate storage for the recirculating pumps and ensures sufficient natural circulation in case of trip-out of the recirculating pumps. These two pumps are of the canned rotor type and provide a zero leakage pumping system; they pump the water through the two secondary steam generators, each consisting of a heat exchanger section and a steam separating section. All joints and connections in the primary loop are welded. The pressure vessel closure is accomplished by double "O" ring gaskets compressed between bolted flanges; no provision is made for seal-welding of the joint.

Three main purification systems for the water are provided:

(1) A condensate demineralizer through which all feedwater flows;

(2) A continuous reactor by-pass demineralizer, which maintains the reactor water purity at a solid concentration of 0.5 ppm;

(3) A make-up demineralizer to purify make-up water entering the system.

Core and Fuel Elements

The fuel used in this reactor is uranium dioxide, compressed and sintered in the form of solid, cylindrical pellets. Uranium will be enriched slightly below 2% in U^{235}; the total weight of the uranium charge in the reactor will be about 91,000 lb. A number of these pellets are inserted in a Zircaloy tubular jacket, having a wall of 0.030 in. thickness, to form one fuel rod section. No bonding agent or filler material is used between pellet and clad. Four such fuel-rod sections are joined by Zircaloy screw connectors to make up the full-length rod, measuring 9 ft 9 in. Finally, 36 full-length fuel rods are assembled in a square 6 by 6 array to form a fuel element, which is encased in a replaceable Zircaloy channel.

The core consists of 384 fuel elements, which rest on the core bottom support plate and are held in transverse alignment at the top by the upper core guide.

The research and design studies carried out by General Electric for the Dresden nuclear power plant have led to the conclusion that cylindrical rod type fuel, clad with Zircaloy of 0.56 in. diameter, was the best choice as far as fuel geometry and cladding material was concerned. Starting from this basic premise the design of the core for the SENN nuclear reactor was evolved, taking into account two major limitations imposed by heat transfer requirements:

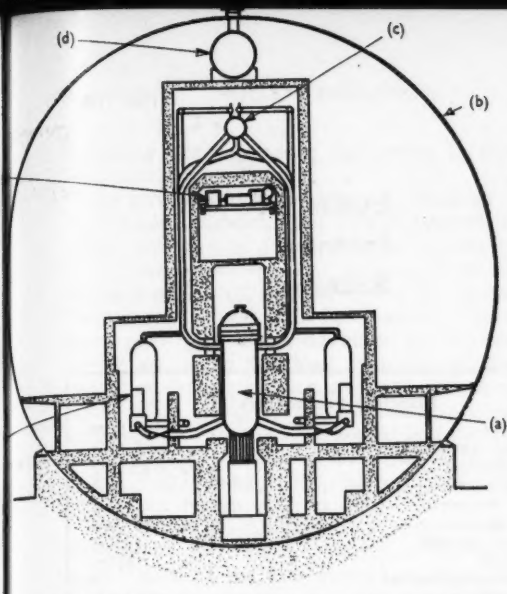
(1) A substantial margin between burn-out heat flux through the jacket surface and actual heat flux was to be maintained;

(2) No melting of the fuel was to be allowed in normal operating conditions. Although the phenomenon of melting is not completely understood, there is evidence that the melting of UO_2, even in a small centreline portion, would increase the release rate of gaseous fission products, and this would tend to increase the internal pressure on the fuel clad. Thus, it might be expected that the fuel clad failure rate would depend upon the degree of UO_2 melting.

The fuel elements are designed to allow an average burn-up of 13,100 MWd/t of initially contained uranium, at equilibrium conditions. Guaranteed burn-up values are in line with the figures quoted in the Euratom-U.S.A. agreement. The fuel loading cycle contemplated provides for the replacement of 20% of the fuel elements every nine months. The maximum resident time of any fuel element in the core is 4.5 years.

Turbogenerator

As already mentioned, the control rods enter through the bottom of the reactor core and are operated by a



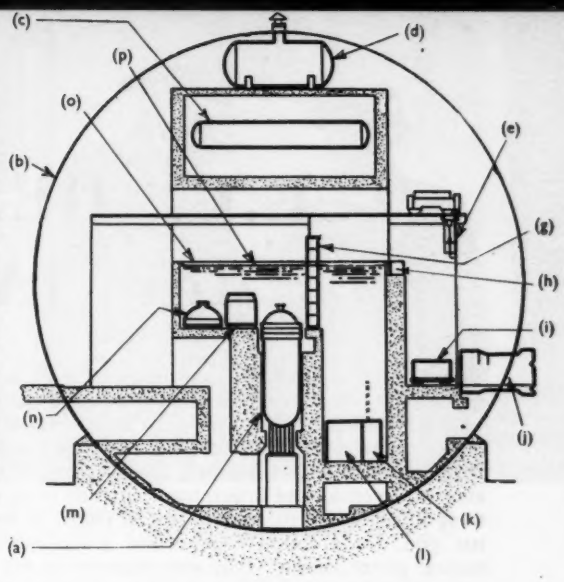


Fig. 3 (left) and 4 (right). —Two sectional views of the reactor enclosure arrangement including the fuel handling apparatus. Key:—(a) Reactor; (b) reactor enclosure; (c) primary steam drum; (d) emergency condenser; (e) crane and removable fuel grapple; (f) secondary steam generator and pumps; (g) removable block wall; (h) removable gate; (i) shipping cask; (j) equipment lock; (k) cask; (l) used fuel storage; (m) turning vane storage; (n) lid storage; (o) working level; (p) water level during refuelling only.

hydraulic system located below the reactor vessel. There are 68 cruciform-shaped control rods, fabricated of stainless steel containing 2.0% boron as the nuclear poison. The functions of the control rods are to start up and shut down the reactor, to set the range of dual cycle automatic control, and shape the neutron flux pattern.

The turbine is of the dual inlet tandem compound double flow exhaust type, with special moisture removal features for handling saturated steam. The capacity is 160,000 kW at 1.25 in. Hg absolute back pressure and the speed is 1,500 r.p.m. It drives a 200,000 kVA generator, with conventional hydrogen cooling. The turbine is designed for 965 p.s.i.a. dry and saturated primary steam, and 475 p.s.i.a. secondary steam. Four extraction steam stages to 375°F are provided to heat the feedwater. By-pass valves are included in the turbine control to discharge steam directly to the condenser in the case of transients which may cause primary steam overpressure.

SAFETY PROVISIONS

The reactor is inherently safe because an uncontrolled rise in reactivity tends to shut down the reactor. In addition the following features of the plant have been incorporated to serve specifically as safeguards against accidents:

(1) Two separate and independently working systems for cooling the reactor. These consist of the main condenser and the emergency condenser. The latter is capable of cooling the reactor following scram and isolation from the main condenser.

(2) Two separate and independently working safety systems, facilitating shutting-down of the reactor and consisting of the control rods mentioned above on one hand, and a liquid poison injection system on the other. The poisoning agent is sodium pentaborate, stored in a tank positioned at a height sufficient to permit entry of the solution into the reactor vessel by gravity.

All safety devices are designed in such a manner that their malfunctioning would shut the reactor down rather than cause, or permit, a rise in its power.

Finally, the 160-ft-diameter spherical containment vessel, will prevent the spread of radioactive fission products into the surrounding areas, even in the event of the reactor vessel or the primary loop fracturing, or the core melting. The sphere is designed for an internal pressure of 22 p.s.i.g. This value equals or exceeds the peak pressure occurring in the hypothetical case of all the hot water being released in an accident. This is the worst form of accident imaginable but it is highly improbable that it would ever take place.

La Centrale d'Energie Nucléaire du Garigliano

Il n'y a guère plus d'un an, un nombre d'entreprises d'énergie électrique et de sociétés de fabrication se sont mises ensemble pour fonder la "Società Elettronucleare Nazionale" (SENN) dans le but de construire une grande centrale d'énergie nucléaire en Italie Méridionale. Avec l'appui du Gouvernement Italien et le soutien de la Banque Internationale de Construction et de Développement, un projet connu sous le nom de "Projet Ensi" a été formulé et 22 sociétés de fabrication dans divers pays furent invitées à soumettre des offres. A la réception, et après examen, des offres reçues, une décision fut prise en faveur du réacteur à eau bouillante et de la fourniture et du montage de l'installation.

La centrale doit être construite sur un emplacement avoisinant l'embouchure du Garigliano sur la côte méditerranéenne d'Italie et le début des opérations de la centrale est prévu pour le premier semestre de 1963 au plus tard.

Das Atom-Kraftwerk Garigliano

Vor etwa über einem Jahr taten sich eine Anzahl Kraftwerks-Unternehmungen und Fabrikations-Gesellschaften der Elektro-Industrie in der "Società Elettronucleare Nazionale" (SENN) zusammen, um ein grosses Atom-Kraftwerk in Süd-Italien zu bauen.

Die italienische Regierung gab ihre Unterstützung, und mit Hilfe der "International Bank for Construction and Development" wurde das sogenannte "Ensi Projekt" formuliert, und 22 Fabrikationsgesellschaften in den verschiedensten Ländern wurden aufgefordert Angebote einzureichen. Nach Eingang und eingehender Durchsicht der erhaltenen Angebote traf man die Entscheidung zugunsten des Siedewasser-Reaktors, und das Werk soll nun geliefert und errichtet werden.

Das Werk soll an einer Stelle nahe der Mündung des Garigliano an der Mittelmeerküste von Italien errichtet werden, und termingemäss soll der Betrieb nicht später als in der ersten Hälfte von 1963 aufgenommen werden.

La Central de Fuerza Nuclear de Garigliano

Hace poco más de un año, diversas empresas de fuerza eléctrica y compañias manufactureras, se combinaron para establecer la "Società Elettronucleare Nazionale" (SENN) con el objeto de construir una gran central de fuerza nuclear en el Sur de Italia. Respaldado por el Gobierno italiano y con el apoyo del "International Bank for Construction and Development," el asi llamado "Proyecto Ensi" fué formulado, y se invitó a 22 compañias manufactureras en diversos paises para que sometieran ofertas. Al ser recibidas las ofertas, previo un escrutionio, se llegó a una decisión en favor del reactor de agua hirviente y del suministro y construcción de la planta.

La central va a ser construida en un solar cerca de la desembocadura del Rio Garigliano en la costa mediterránea de Italia, y está programada para comenzar operaciones no más tarde del primer semestre de 1963.

G.E.C. DESIGN for JAPAN

Letter of Intent Received

A LETTER of intent was sent on April 3, by the Japan Atomic Power Co. to the General Electric Co. of England, concerning the construction of a 150-MW nuclear power station to be built at Tokari-Mura, approximately 70 miles north-east of Tokyo. After a detailed examination of American and British types currently being offered, three British consortia were invited to tender in February last year, for a 150-MW gas-cooled graphite-moderated nuclear power station. Bids were received by the end of July and at the end of February this year it was announced that detailed negotiations were to be opened with the G.E.C., Simon-Carves Group.

It is now expected that final negotiations can be concluded in the next two months and that a contract will be placed in July. Work on the station is expected to start in October, allowing first electricity production to the local grid network at the end of 1963.

A Japanese delegation under Dr. Tamaki Ipponmatsu, vice-president of J.A.P.C. arrived in the United Kingdom on March 24, to conclude an agreement with the AEA which appoints the Authority as design consultants, and to continue negotiations on fuel supplies and burn-up guarantees. A letter of intent has been sent by the AEA covering the supply of fuel, but negotiations are continuing over the final details of this agreement and those concerning burn-up; a figure of 3,000 MWd/ton has been mentioned.

The value of the total contract which will be placed with the G.E.C. is in the region of £20 million. Earlier this year it was announced that the company had concluded manufacturing agreements with a consortium of 14 Japanese companies known as the Fuji Group. The value of contracts to British manufacturing concerns will be in the region of £9 million of which £4 million will be handled by the G.E.C. itself.

Design Evaluation

The J.A.P.C. were concerned with three major aspects of design, viz., anti-earthquake protection, safety and general engineering. A special committee was set up in Japan to examine the various problems arising from earthquake risks and to ascertain whether, under seismic shocks the graphite stack would move as a body or break up. A one-third scale model was built and a 40-ton vibration machine constructed capable of applying static forces equivalent to 0.7G and dynamic forces equivalent to 1G, allowing measurements to be made of the stack behaviour when subjected to horizontal accelerations of 1G and vertical accelerations of ½G. The analyses of the core strains and stresses were published earlier this year; they showed that the graphite would remain as an integral body. Studies are continuing on the effect of earth tremors on plant components, such as the tubing in the heat exchangers.

On the safety side the J.A.P.C. received the assistance of the Atomic Energy Authority. Meteorological investigations are continuing to complete detailed site data. During the safety study on the reactor, Wigner growth and positive temperature coefficient received much publicity. According to Dr. Ipponmatsu, these were terms bandied about by schoolboys in Japan.

Principal Parameters

Net capacity	150 MW
Completion scheduled	end 1963
Turbo-generators	2 × 85 MW
Reactor p.v. i.d.	62 ft
P.v. plate thickness	3½ in.
Wt. of graphite	1,500 tons
No. of fuel channels	2,056
Lattice pitch	8¼ in.
No. of elements/channel	8
Coolant pressure	~ 185 p.s.i.
Dia. of main ducts	6 ft
No. of heat exchangers	4
Dimensions of H.E.s	21½ ft dia. × 84 ft
Shielding concrete	10 ft

In a technological evaluation made by a team of over 100 engineers with the co-operation of the Universities, the conclusion was drawn that, although the design submitted by the three consortia differed in many respects, no one design could be preferred on technical grounds alone. As a result the final choice was made in terms of the economics of the plant and in the guaranteed cost per unit sent out.

G.E.C. Design

The G.E.C. design although evolved from Hunterston differs in a number of ways. The most striking feature is the adoption of top charge/discharge to keep the centre of gravity of the plant as low as possible. The reactor and four heat exchangers are built on a single cellular raft extending to 50 ft below ground level, with the heat exchangers raised on local plinths to promote natural circulation in the event of blower failure. All items on the raft are firmly anchored to the 10 ft biological shield and great care has been taken in the design of support systems to ensure that stresses are maintained at safe levels. The spherical reactor pressure vessel which is mounted on a supporting skirt, is also provided with a top skirt to brace the upper half of the sphere to the biological shield. The turbine house is on separate foundations, provision being made for considerable flexibility in the overhead steam mains. In the event of any rupture in the secondary coolant system the reactor will shut down and the residual heat will be taken up by evaporation of water contained in tanks mounted on the main reactor raft.

The core of the reactor is a 32-sided cylinder pierced by 2,056 fuel channels, each carrying 8 elements. These elements are similar in design to the Hunterston elements, the can being supported in its own impermeable graphite sleeve which transmits the thrust from the elements above. Magnox canning is used and although full details of the fuel elements have not been released, as a similar design has been submitted in the Trawsfynydd tender, they are known to be hollow. Although the lattice pitch is the same as at Hunterston, viz., 8¼ in., it has been found possible to increase the channel rating without sacrificing undue reactivity by reducing the temperature gradient within the rods and improving the heat transfer. This has necessitated

increasing pumping power, but results in better over-all economics.

The core is held in the pressure vessel on an egg box diagrid and is surrounded by a rigid cagework, the restraint system representing a major design feature of the anti-earthquake measures. The pressure vessel is of 3¼ in. steel and is 62 ft i.d. (compared with 2⅞-3 in. and 70 ft for Hunterston). Access to the fuel channels is through vertical stand pipes and charge/discharge and servicing can be carried out under full load from one of two machines located on the charge floor, equipped with zirconium alloy grabs. Each charge machine is remotely controlled by a single operator from a desk housed in a room at the edge of the pile cap. Computer techniques have been adopted in the programming of the charge machine operations, a punch card system ensuring correct sequence control.

Four steam raising units are provided, each 21 ft 6 in. diameter by 84 ft high, connected to the reactor by 6 ft ducts. Each of the four blowers is mounted within the shell at the bottom of a heat exchanger, and is driven by its own individual steam turbine.

Emergency Shut-down

A novel emergency shut-down system has been devised to back up the normal control rod operation. Hoppers containing 1-in. boron steel balls are mounted within the pressure vessel above the core and these can discharge their contents down special channels left in the core structure, from which they can be subsequently removed by a concentric pressure/exhaust tube, carried by the charge/discharge machine. Ejection of the balls into the core can be initiated by manual operation, or by signals from seismic detectors located on the station site, or by displacement indicators mounted at various key positions within the reactor system. These last give warning of any mechanical failure and notably of any movement of the core within the pressure vessel.

Two customers confer; Dr. Ipponmatsu, vice-president of J.A.P.C. and Mr. J. Henderson, chief engineer of S.S.E.B.

Contrat G.E.C.—Japonais

La Société d'Energie Atomique du Japon a envoyé une "Lettre d'Intention" à la "General Electric Co." à l'égard de la fourniture d'une Centrale à Energie Nucléaire du type "Calder" de 150 MW à être construite à Tokai-Mura, à une distance de 112 Km. environ de Tokio. La conception comprend la prise de dispositions pour chargement et déchargement supérieurs avec la centrale fonctionnant au maximum éléments de combustible creux, commande à turbine à vapeur pour les souffleurs et un système d'interruption d'urgence qui implique l'injection de billes d'acier au bore en chambres spéciales.

G.E.C. Kontrakt für Japan

Die japanische Atomkraft Gesellschaft hat in einem Brief an die General Electric Co. die Bedingungen mitgeteilt, die für die Lieferung eines 150 MW-Atom-Kraftwerkes in Frage kommen, das bei Tokai-Mura 112 km von Tokio entfernt gebaut werden soll. Der Entwurf zeigt Brennstoff-Zuführung von oben und Abführung ohne Unterbrechung des Betriebes, hohle Brennstoff-Elemente, Dampfturbinenantrieb für die Gebläse und ein Not-Absperrsystem, das mit der Injektion von Borstahl-Kugeln in besondere Kammern arbeitet.

Contrato G.E.C.—Japones

La Compañia de Energia Atómica del Japón ha enviado una "Carta de Intención" a la "General Electric Co." relacionada con el suministro de una Central de Energía Nuclear de 150 MW del tipo "Calder," que ha de ser construida en Tokai-Mura a unos 112 Km. de Tokio. El diseño incluye disposición para carga y descarga superiores con la Central funcionando a plena potencia elementos de combustible huecos, mando por turbina de vapor para los sopladores y un sistema de interrupción de emergencia que implica la inyección de bolas de acero al boro en cámaras especiales.

Graphite Machining, pages 206-215

Usinage du Graphite

L'introduction du programme britannique de centrales d'énergie nucléaire basées sur des réacteurs modérés au graphite et refroidis au gaz, a créé une demande exceptionnelle pour des blocs et carrelages en graphite usinés. Chacun des quatre consortiums construisant des centrales d'énergie nucléaire a pris ses propres dispositions pour l'usinage du graphite. En outre, la U.K.AEA possède ses propres ateliers d'usinage de graphite à Windscale. Le présent article discute, du point de vue de l'ingénieur en machines-outils, des problèmes entraînés par l'usinage de grandes quantités de graphite de qualité nucléaire selon des configurations complexes et des tolérances très précises.

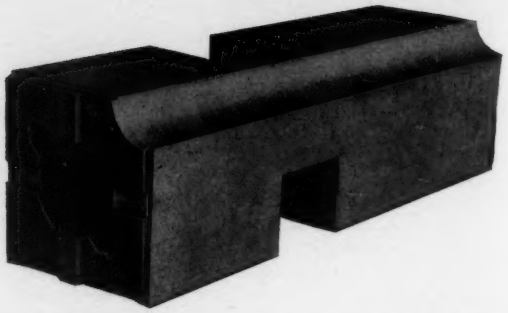
La production de blocs modérateurs exige aussi des conditions de propreté absolue pour empêcher la contamination. Chacun des quatre ateliers se sert des nouvelles idées en matière d'usinage du graphite et les diverses méthodes employées sont examinées assez détaillément

Mechanische Bearbeitung von Graphit

Die Aufstellung des britischen Programms für Atom-Kraftwerke auf der Grundlage von gas-gekühlten Reaktoren, die mit Graphit als Moderator arbeiten, hat eine ausserordentliche Nachfrage nach mechanisch bearbeiteten Graphit-Blöcken und -Platten hervorgerufen. Jedes der vier Konsortien, die Atom-Kraftwerke bauen, hat seine eigenen Anordnungen zur mechanischen Bearbeitung von Graphit getroffen. Ferner hat die U.K.A.E.A. ihre eigene Graphit-Bearbeitungs-Werkstatt in Windscale. Der Aufsatz diskutiert vom Standpunkt des Werkzeugmaschinen-Ingenieurs die Probleme, die bei der Bearbeitung grosser Mengen Graphits von nuklearer Reinheit auftreten, die verwickelte Formen haben, die mit geringsten Toleranzen fertiggestellt werden sollen. Die Herstellung von Moderatorblöcken erfordert weiter absolute Reinlichkeit, um Verseuchung zu verhindern. Jede der vier Werkstätten wendet neue Ideen für die Bearbeitung des Graphits an, und die verschiedenen Methoden, die benutzt werden, werden in einigem Detail beschrieben.

Mecanizado de Grafito

Le presentación del programa británico para centrales de fuerza nuclear basadas sobre reactores moderados a grafito y enfriados a gas, creó una demanda excepcional por bloques y bladosas de grafito mecanizado. Cada uno de los cuatros consorcios que están construyendo centrales de fuerza nuclear ha hecho sus propios arreglos para el mecanizado de grafito. Además, la U.K.AEA (Autoridad de Energía Atómica Reino Unido) tiene su propio taller de tratamiento de grafito en Windscale. Este artículo discute, del punto de vista del ingeniero de máquinas herramientas, los problemos que significan el mecanizar grandes cantidades de grafito de calidad nuclear a una configuración compleja y a tolerancias ajustadas. La producción de bloques moderadores también exige condiciones de escrupuloso aseo para evitar la contaminación. Cada uno de los cuatro talleres de mecanizado hace uso de nuevas ideas sobre el mecanizado de grafito y se describen los distintos métodos detalladamente.



Graphite reflectors for all the DIDO family of reactors were machined at Windscale. The reflector on the left is for the Danish DR3 reactor which is being built by Head Wrightson.

Core bricks for Berkeley present a particularly difficult machining problem as the fuel channel has to be broached to accommodate fuel element support struts.

Graphite Machining

A graphite moderated nuclear power station with an output of 300 MW requires from 4,000 to 5,000 tons of finished graphite components. This article describes the machining techniques employed in four British establishments.

LAST month we discussed the production of nuclear quality graphite at Anglo Great Lakes' new factory at Newburn Haugh. There are, in fact, two prime sources of nuclear graphite in the U.K. for, in addition to Anglo Great Lakes, British Acheson Electrodes of Sheffield have extensive manufacturing resources. The entire output of nuclear-grade graphite from both factories is purchased by U.K. AEA.

At the present time part of the output is sent for machining at Windscale works whilst the remainder is dispatched to one of the four graphite machine shops established by British industry to meet the requirements of the gas-cooled graphite moderated power reactor programme.

There are thus five major establishments concerned with the machining of nuclear graphite. The first of these at Windscale was formed in 1948 to cater for the U.K. AEA's own requirements. In the past year or so, however, each of the four consortia engaged on the construction of a nuclear station has established separate graphite machining facilities. Adjacent to Anglo Great Lakes' factory at Newburn Haugh, A. Reyrolle are machining components on behalf of N.P.P.C. for the Bradwell reactors. Near Poole, in the old Royal Ordnance factory, Nuclear Graphite is machining graphite for Berkeley, whilst at Hayes, Middlesex, Powell Duffryn Carbon Products have recently begun work on the moderator components required by G.E.C. Simon-Carves for Hunterston. The fourth shop has been established by English Electric at Whetstone, near Leicester.

These then, are the five major nuclear graphite machining facilities in the U.K. They are supplemented by a number of specialized units which are capable of producing one-offs or small batches of components for experimental purposes. At the Gosport works of Graviner Manufacturing special techniques have been evolved for producing complex configurations to close tolerances in nuclear purity graphite.

The methods employed in machining graphite are not particularly new, although it may not be generally realized that until graphite was adopted as a moderator by the AEA only comparatively small quantities were being machined in the U.K.

So far as nuclear graphite is concerned pioneer work was carried out at A.E.R.E., Harwell, when the first blocks were produced for GLEEP and BEPO.

When, in 1948, work started on the plutonium producing piles at Windscale it was decided to machine the graphite on site and many of the machines at Harwell were transferred to the new shop. For 10 years Windscale housed the only large graphite machine shop in the U.K.

The shop's responsibilities during this period were formidable. All the blocks for both the Windscale piles, graphite reflectors for all the DIDO, PLUTO family and more recently all the graphite necessary for the four Calder and the four Chapelcross reactors were machined to exacting tolerances against a tight time schedule. In addition the shop has also produced, on a quantity basis, a wide variety of graphite components such as nozzles and crucibles for casting uranium and so on. Frequently the shop has had to contend with major changes after production had started. It has also tested and evaluated new machining techniques from time to time. In view of the extensive experience of both management and operators at Windscale, it is a matter of regret that when the last Chapelcross blocks are completed in the next few weeks a large section of the machine shop will become redundant.

In view of the partial closure of the Windscale machine shop it would appear that the decision three years ago that each consortia should establish its own machining

facilities for graphite was highly contentious as being wasteful both from the point of view of manpower and of capital investment. It must be remembered, however, that each of the consortia has designed its own moderator structure and that the features differ considerably in each case. Secondly, the time factor is too short to enable one machine shop to handle all the graphite required for the eight power reactors in course of construction in the U.K. Furthermore, if one accepts the challenge of commercial competition, in spite of some duplication (or possibly quadruplication!) of effort, there is greater promise of improved production techniques leading to a lowering of the present high machining charges.

At this point it would be pertinent to discuss the special factors involved in producing graphite moderator components. Clean conditions are a first essential: under no circumstances must the graphite be subjected to contamination by water, lubricating oils and greases, nonferrous metals such as copper, brass, lead, cadmium nickel or any other material which might affect the capture cross section of the moderator. It is particularly important to ensure that operators do not touch the blocks with bare hands, and protective clothing comprising overalls, gloves, caps and shoes must be worn.

A graphite machine shop is invariably arranged so that personnel cannot enter the clean conditions area without changing into the special clothing. No smoking is permitted and no food must be brought in. Canteen facilities are usually adjacent to the changing room area so that operators do not have to change their clothing during a short meal break.

So far as the handling of graphite is concerned provision must be made for storing large quantities of raw blocks and machined blocks in such a way that transport vehicles can be loaded and unloaded in clean conditions. In the machining area a highly efficient dust and swarf removal system is essential. It has been found advantageous to run the air-conditioning system at a slight pressure to prevent the ingress of dust-laden air through doorways or ventilators.

Next, the choice of machines and the layout of the shop. Nuclear grade graphite is not difficult to machine but the required tolerances must be strictly adhered to and the bricks or tiles must not be damaged in any way during operations.

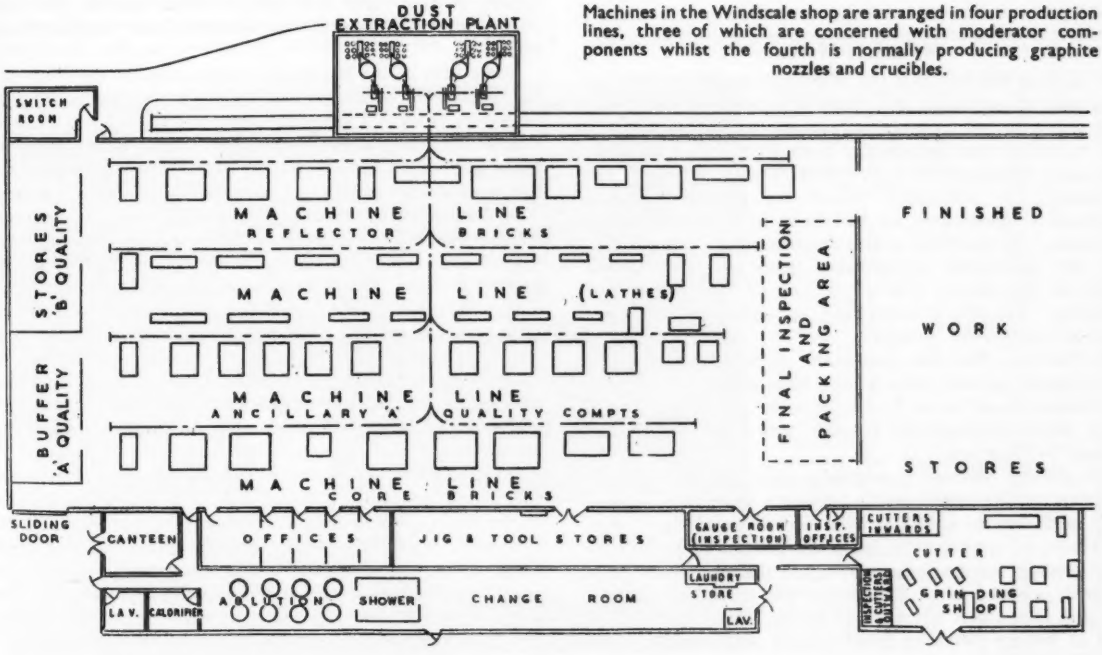
An important feature of every installation must be flexibility: the design of a graphite pile is likely to change at short notice. Following the Windscale incident, for example, the Authority decided that the effects of Wigner growth could be counteracted by insertion of a graphite sleeve in the fuel channel. This requirement has obviously necessitated a major change in the design of both bricks and tiles.

In most cases flexibility has been achieved by organizing machine tools in correct sequence for a particular series of operations and then providing roller tables so that blocks can be manually transferred. As raw blocks weigh over 1 cwt., hydraulic- or air-operated equipment is used for lifting blocks into position. Special air-operated clamps with large pressure pads steady the blocks during the actual machining operation.

In each of the four machine shops described later in this article a slightly different approach has been adopted so far as the choice of machine tools is concerned. In general, however, bandsaws are used to trim the blocks approximately to size or to make planks for tiles. Milling machines reduce the exterior faces to finished size. Special features to assist the interlocking of bricks and tiles are also obtained by milling. The fuel channel may be bored or trepanned. At one establishment blocks are bored and broached.

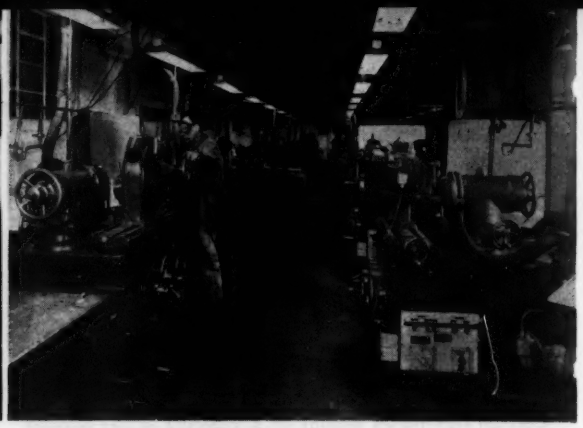
Throughout the machining operation there must be systematic checking to ensure that components are correctly sized. Damage can result from undue strain during machining or by careless handling when the block is being transferred. Again, before packing the block or tile prior to dispatch all dimensions must be finally checked.

Nuclear-grade graphite is an abrasive and although the



Machines in the Windscale shop are arranged in four production lines, three of which are concerned with moderator components whilst the fourth is normally producing graphite nozzles and crucibles.

In addition to moderator components, Windscale turns small graphite parts on conventional lathes.



Most of the milling machines at Windscale are standard units modified as a result of operational experience.

load on the cutters is low, the life of the cutting tool is short. In general terms the practice is to change cutters once per shift when high-speed steel is the cutting medium. A longer run can be obtained by using tungsten carbide tipped tools. Excellent results have also been obtained with hard ceramic tools such as Sintox.

The short life of the cutters means that each shop must have a self-contained cutter grinding section. Here again rigorous clean conditions must be observed and coolants must not be used during the grinding operation.

As previously mentioned, an important aspect of graphite machining concerns the removal of dust and swarf. From the raw block to the fully machined stage something like 50% of the volume of the block is removed.

Because of the abrasive nature of the dust all machine tool bearings must be completely sealed. It is also necessary to enclose all slide ways, lead screws and similar working surfaces. The problem of swarf and dust removal is generally overcome by the installation of a centralized vacuum dust-extraction system with downpipes and hoods taken as close to the cutting head as possible. Outside the machine shop a swarf bagging and dust filtration equipment is installed.

Turning now from a general description of the factors involved in graphite machinery to specific practices, it is appropriate that we should mention the Windscale shop first.

Windscale Works

In spite of the fact that the Windscale machine shop has been built up gradually as a result of experience, the layout and sequence of operations follows a logical pattern. There are four main production lines: core bricks; ancillary A quality components; lathes, and reflector bricks. The installation is essentially based on standard milling machines supplemented by bandsaws and vertical boring machines. As the shop is also responsible for the production of specialized components such as nozzles and crucibles for casting uranium a line of lathes has been included. Recently a multi-head bar automatic has been adapted for turning nozzles.

To facilitate flow line production on the more common components jigs and fixtures have been made up. In each line machines are linked by simple roller conveyors, boards being placed between the graphite and rollers to prevent damage by chipping.

The cutting material is normally high speed steel. Both tungsten carbide tipped tools and Sintox have been successfully used, but the shop has been tied to H.S.S. because of the stocks of cutters built up in the process of handling a large tonnage of graphite in the past three or four years. Normal practice is to change cutters once per shift: a side and face cutter averages 65 passes. A cutter which is kept in service too long breaks down very rapidly—only about five passes occur between the first signs of deterioration and unacceptable roughness.

The graphite machine shop at Windscale has made a number of original contributions to the technique of graphite machining. For example, the feed rate for components has been progressively stepped up from 40 in./minute to 100 in./minute. A 12-in. diameter cutter with 20 teeth running at 350 r.p.m. has a feed per tooth of .015 in. Slower-running cutters tend to cause flaking of the edges of the block.

In the early days the charge channels in the Windscale piles were produced by milling semi-circular features across the bricks so that when the two bricks were brought together a circular channel was formed. Because of cross-channel leakage at the joint faces the Calder bricks were designed with channels bored through the length of the bricks. At first horizontal borers were used but a number of problems were encountered: swarf removal was difficult, the rate of cutter wear was high and there was deviation of the bore at the finishing end of the block. In collaboration with Archdales, however, a vertical borer was developed—initially by modifying a large multi-spindle drill. The boring bar was fixed to the machine base and driven by a separate motor through a bevel gearbox and the component was fed downwards to the cutter. On subsequent machines the feed was transferred to the boring spindle so that rapid fore and aft adjustment of the table could be made in order to accommodate various brick sections.

Some idea of the sequence of operations in the shop can be gained by following the various stages in the production of a core brick. The rough block is trimmed on a bandsaw before being passed to a duplex miller where opposite faces are milled simultaneously. For the next operation the block is turned 90° and the other two faces are milled. The block is then checked for accuracy and squareness. The vertical borer makes use of a special cutter comprising two blades taking a rough cut followed by four blades to finish the bore. Each bore is inspected before the block is passed to a horizontal mill where one corner is radiused. Operations 6 and 7 on a wide duplex mill and a vertical mill are both concerned with the provision of keys and keyways for interlocking blocks and tiles in the pile. Close tolerances are called for at this stage and blocks are inspected after each machining operation before being passed to the final inspection bench.

For the Chapelcross reactors it was necessary to revise the production line in order that a sleeve could be cut in the block in addition to the removal of a central bore. Following a period of trial research carried out by Powell Duffryn Carbon Products, machines were devised which would trepan the sleeve and the bore at the same time. Two machines loaned to the Authority by Powell Duffryn have produced over 30,000 sleeves in this way.

Powell Duffryn Carbon Products

Graphite has been machined at the Hayes works of Powell Duffryn Carbon Products for many years. The company's extensive experience served in good stead when it was decided to establish a machine shop for nuclear graphite.

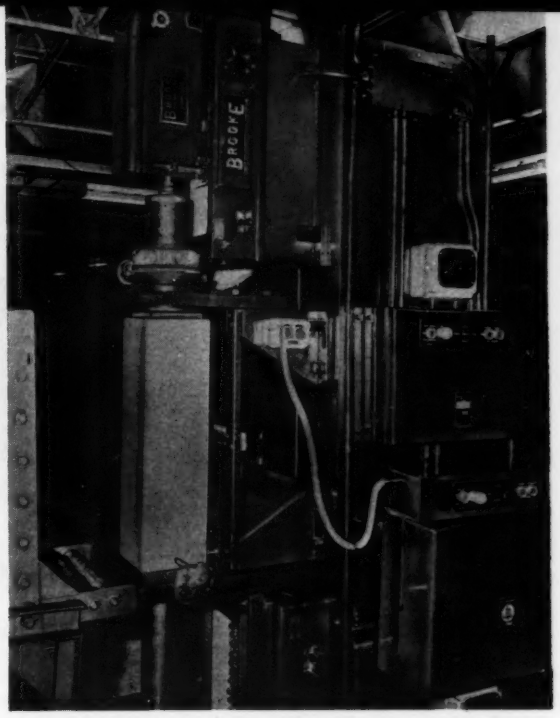
Among other jobs, Powell Duffryn have supplied a new graphite core for BEPO, the inner radiation barrier for ZENITH, and the pile for the exponential experiment at Imperial College, London. The company has made a significant number of contributions to the technique of machining moderator components. Of special interest is the ingenious method of trepanning blocks to produce a fuel channel bore and sleeve simultaneously. In the case of the Hunterston bricks—which the company is machining on behalf of G.E.C. Simon-Carves—a special form of sleeve is produced.

The new graphite machine shop at Hayes has six production lines: one each for Hunterston core bricks, tiles and reflector components together with a small line for finishing sleeves; for trepanning Bradwell bricks; and for producing struts for Berkeley.

As a result of their previous experience of machining graphite, Powell Duffryn developed a special type of machine for milling. Machines for such operations as trepanning of the fuel element sleeves were also specially designed as no suitable units existed that could be modified.

The milling machines are, in fact, built up from standard units, the first being a completely self-contained electro-mechanical travelling table, with its own motors, trips, fast and slow traverse and return mechanisms, fully protected slideways, leadscrews, and electrical equipment. The second unit is a self-contained unit head and wing base, with built-in electrical and mechanical systems, and a specially designed quill retraction unit for the prevention of back cutting during fast return of the table to the loading position.

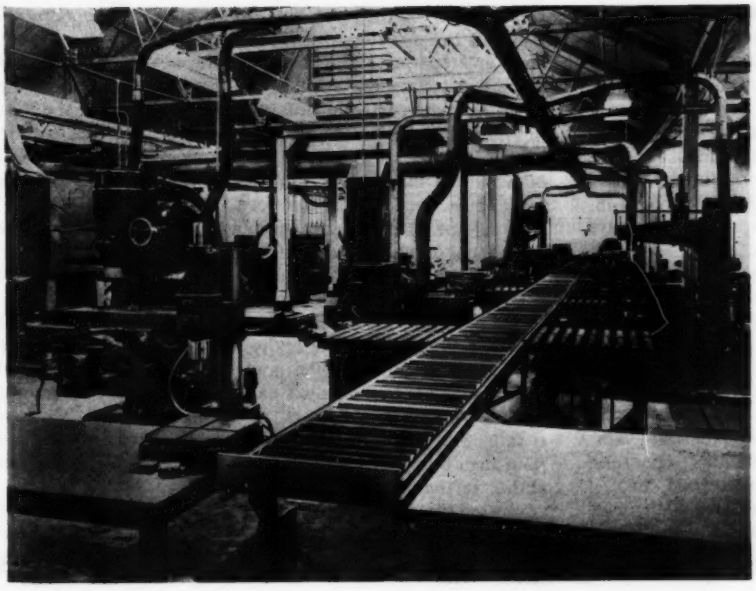
These two self-contained units, developed in conjunction with Brooke Tool can be built up to form plain or duplex milling machines, interconnected electrically, and with varying spindle heights. The heads can be closed together across the table, or retracted to 40 in. apart, and they can be fitted with a variety of attachments for multi-head milling, drilling, etc., such as is used on the moderator block.



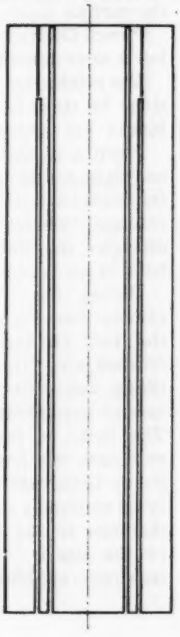
Trepanning machine developed by Powell Duffryn in conjunction with Brooke Tool for the simultaneous production of graphite sleeves and fuel channel bores.

The machines are interlinked by roller conveyors, and the fixtures are all air operated. Mechanical breakdowns can be quickly cleared by the removal of the faulty unit and replacing it with a spare. The machines can also be formed into varying production units as required.

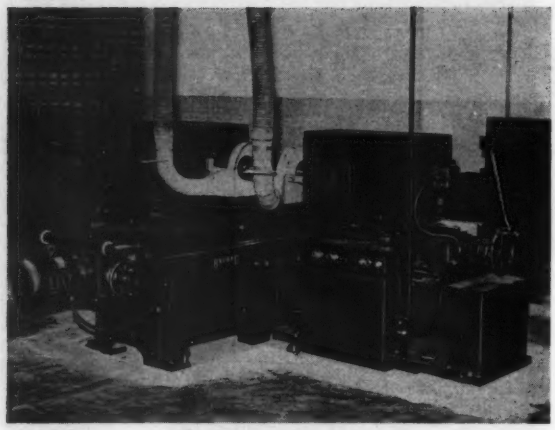
Turning now to the cutting tool it was decided that the hardest possible cutting material should be chosen consistent with the material having sufficient impact resistance to withstand the stresses imposed upon it during machining operations. Because the cutting loads are low, Powell Duffryn decided that the hardest obtainable grades of sintered carbide could be used to great advantage. Although extremely brittle and quite unsuitable for some of the severe loads imposed during the machining of metals, these grades are

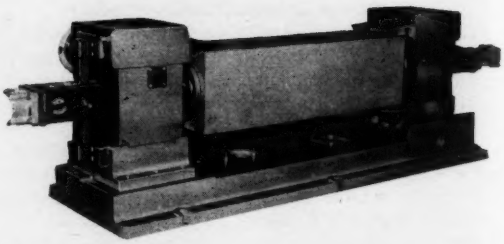


General view from the inspection end of the Powell Duffryn line for producing Hunterston core bricks.

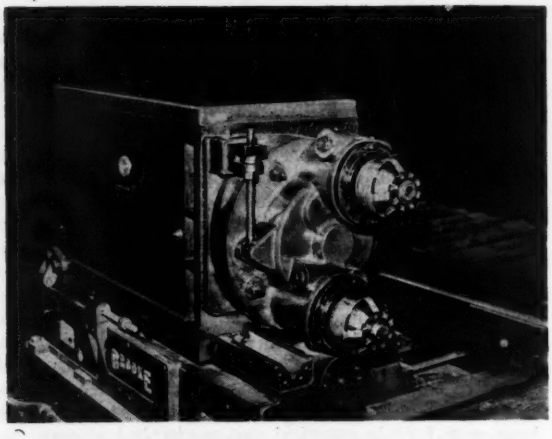


Section through Hunterston brick showing the three trepanning cuts. On removal from the machine the operator taps the block to sever the thin skin left at the top of the core and the shoulder of the sleeve.





(Above) Fixture for accurate location of Hunterston blocks. (Left) Duplex miller with unit heads for machining opposite faces of the block simultaneously. (Below) Unit head with planetary system for milling end features.



quite successful when employed for graphite machining. Life between regrinding is at least four times greater than can be expected with 18% tungsten high-speed steel. Tungsten carbide tools are used for all operations, except in a few instances when cheap tools are required for comparatively short runs.

Although standard milling cutters, as utilized in cutting steel, cast iron, or non-ferrous metals will operate satisfactorily on graphite it was known that they would not be entirely suitable, and the milling cutters were designed for graphite machining. The various rakes, angles, number of teeth and peripheral speed were adjusted to obtain the best results.

Using a pair of 12-in.-diameter face milling cutters it has been found possible to fully machine all four faces of approximately 200 moderator blocks between regrinding. The same type of tip material is also utilized in the design of the special trepanning cutters. Experience has shown that with correctly adjusted feed and speed rates it is possible to produce some 200 graphite sleeves between regrinds. Wear due to abrasion on the tungsten tips seldom affects the dimensional stability of the components and often the only indication that regrinding is necessary, apart from an examination of the tips, is a progressive deterioration of the surface finish.

Powell Duffryn's regrinding section is comparatively small but it does contain a fully automatic regrinding machine.

The production of a Hunterston moderator block is shown stage by stage in an accompanying illustration. The raw blocks are approximately 9 in. square by 30 in. long.

From a platform which can be hydraulically raised to conveyor height, as layer by layer of the pallet is cleared, the blocks are taken by roller conveyor to a duplex milling machine, where the two ends are sliced off by 24-in. diameter tungsten carbide tipped cutters; the blocks are held in an air-operated clamping fixture.

During the trepanning operation the graphite fuel-element sleeve is removed from the centre of the block and the fuel channel bore is machined simultaneously to finished size. The component is elevated in an air-operated tilting mechanism and clamped in the machine. Three special trepanning cutters are employed in the operation. The first, or inner, cutter removes a waste core and machines the finished bore of the sleeve, operating vertically from below. The second, or outer cutter, operating in an extremely narrow annulus, bores the finished channel diameter in the block and machines the outer diameter of the sleeve. The third cutter, operating in an even narrower annulus traverses down from above to almost meet the second or outer cutter traversing from below. All cutters are then retracted and the core, sleeve and outer block removed from the machine. The combination of these three cutters operating simultaneously produces a sleeve with a parallel bore and two outer diameters. The main problem was to design cutters which would operate in such a narrow annulus, produce a sleeve and bore within ± .005 in. on all diameters, and within ± .001 in. on parallelism and concentricity. Further arrangements had to be made whereby the dust produced could be removed from all three cutters during the operation.

After trepanning the four long faces of the block are machined. Extreme accuracy is required; all four faces must be made perfectly square to each other, and the bore in the finished block must be within ± .0025 in. of the centre line at both ends. It was decided in the interest of accuracy that it was more practicable to machine the block faces locating off the bore.

A pair of short expanding mandrels are located into the two ends of the block before loading into the fixture. These mandrels have female centres and are located in a pair of live male centres running on taper roller bearings. During loading these centres are closed into the mandrels and the block located laterally by a pair of air operated fully compensating parallel jaws, holding the block against rotation. The work is then passed between duplex milling cutters, fast traversed back to the loading position, the parallel jaws are retracted and the block rotated 90°, the jaws then being closed, locating on the two machined faces and a further pass taken through the machine.

During the period that this particular fixture was utilized for the machining of some 650 blocks for the Imperial College of Science exponential stack, it was found to be

accurate within 0.0005 in. on squareness of adjacent faces.

The block is next passed between cluster cutters on a Duplex milling machine to produce the seal face and locating keys at the ends of the block. A similar operation is performed during the fifth stage, except that a special purpose head is employed to produce the locating rebates. This special head is designed on the planetary principle and can be revolved on its centre to take up reduction in diameter of the cutters due to peripherial grinding. It is thus necessary only to ensure that the relevant cutters are paired as regards diameter, any required setting changes being obtained by revolving the planetary head and re-clamping it.

Operation 6 is a conventional milling operation to produce the control rod fillet, and is carried out on a plain milling machine. The finished block is now taken by roller conveyor to a Sigma Liquicolumn inspecting machine, where all dimensions are inspected simultaneously and a visible indication shown of the measurements taken. The component is then stamped with a part number and passed to a packing station where it is packed in a corrugated cardboard container and sealed with tape.

The Hunterston tile and production line comprises nine operations: rough cropping, plank cutting, tile cutting, boring, three milling operations to establish dimensions and generate step and angles on two edges, vertical trepanning to produce the control rod fillet and grooving for the thermocouple slot.

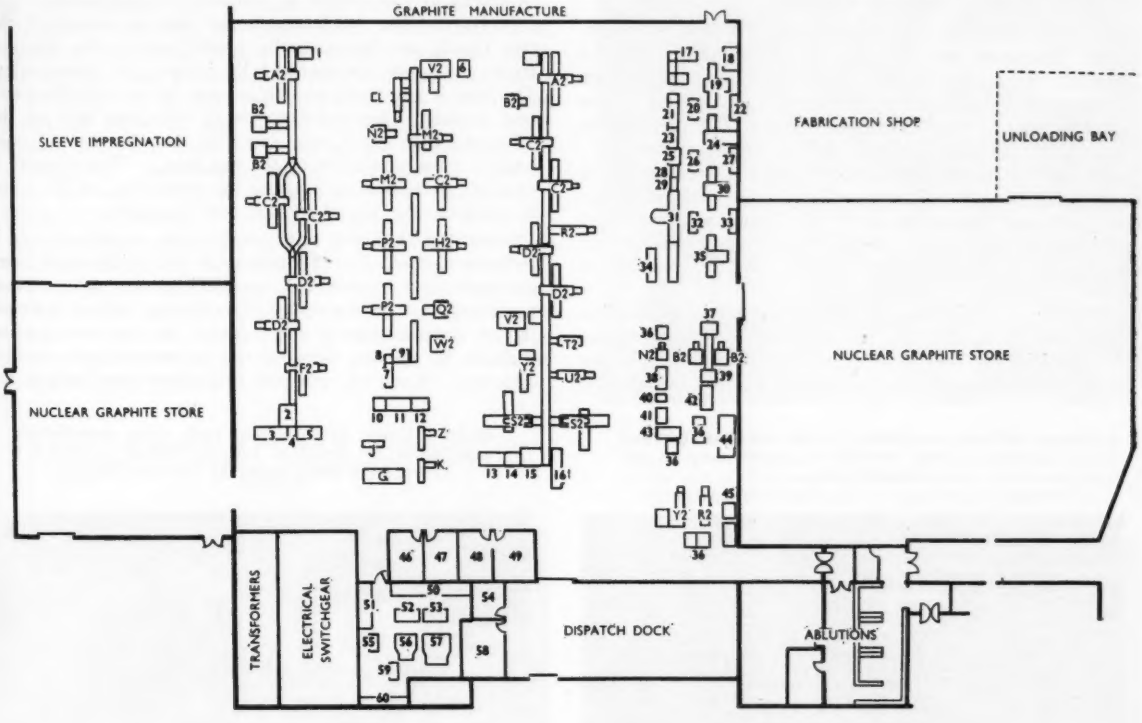
After trepanning on the brick line it is necessary to finish machining the graphite sleeve after it has been rendered impermeable in another part of the shop. These operations involve forming a cup at one end of the sleeve and a mating cone on the other, a series of grooves to form the labyrinth seal and a number of internal slotting operations for the fuel cannister centering spiders.

Hunterston reflector components are machined on another line on a batch production basis.

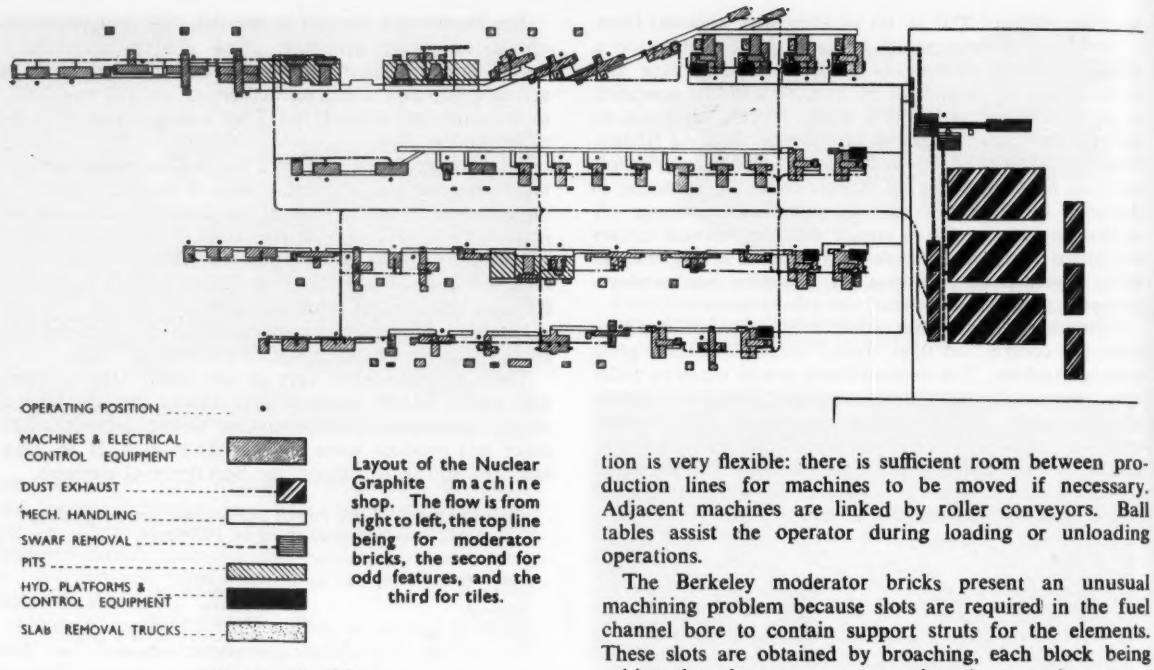
There are two other lines in the shop. One of these will trepan 52,000 Bradwell core blocks and machine a similar quantity of interconnecting spacer sleeves. The other will produce some 200,000 struts each 21 in. long and 1 in. square to support the Berkeley fuel elements.

(Below) Layout of the Powell Duffryn new nuclear graphite machine shop at Hayes, Middlesex.

A2	DUPLEX MILLER	H2	DUPLEX MILLER	N2	TREPANNER	T2	RADIAL DRILL
B2	TREPANNER	J	CAPSTAN LATHE	P2	DUPLEX MILLER	U2	HORIZONTAL DRILL
C2	DUPLEX MILLER	K	KEYSEATER	Q2	TREPANNER	V2	BANDSAW
D2	DUPLEX MILLER	L	CAPSTAN LATHE	R2	HORIZONTAL	W2	SPINDLE MOULDER
F2	PLAIN MILLER	M2	PLAIN MILLER	S2	VERTICAL MILLER	Y2	HORIZONTAL BORER & FACER
G	COPY LATHE					Z	KEYSEATING MACHINE



1	LIFTING PLATFORM	16	STORAGE	31	X-RAY	46	SHOP SUPERINTENDENT
2	RECEIVER GAUGE	17	SPEC M C	32	BENCH	47	INSPECTOR
3	PACKING	18	TOOL SETTING	33	TOOLS	48	CHIEF INSPECTOR
4	STAMP	19	HORIZONTAL MILL.	34	PACK	49	INSPECTION
5	STORAGE	20	BENCH	35	HORIZONTAL MILLER	50	CUTTER RACKS
6	LIFTING PLATFORM	21	4 SPINNER GRINDER	36	PALLET	51	CUTTER RACKS
7	PACKING	22	TOOLS	37	LIFTING PLATFORM	52	BENCH
8	STAMP	23	BENCH	38	CAPSTAN	53	BENCH
9	GAUGE	24	HORIZ. MILLER	39	SURFACE TABLE	54	DISPATCH CLERK
10	PALLET	25	INSPECTION	40	MILLER	55	GRINDER
11	PACKING	26	BENCH	41	SURFACE TABLE	56	WALTER GRINDER
12	GAUGE	27	TOOLS	42	PACKING	57	WALTER GRINDER
13	PACKING	28	BENCH	43	PACKING	58	INSPECTION GAUGES ETC.
14	SURFACE TABLE	29	STAMP	44	SMALL PIECE LATHE	59	GRINDER
15	GAUGE	30	HORIZONTAL MILLER	45	SURFACE TABLE	60	CUTTER RACKS



Layout of the Nuclear Graphite machine shop. The flow is from right to left, the top line being for moderator bricks, the second for odd features, and the third for tiles.

Nuclear Graphite

Nuclear Graphite—a company jointly owned by A.E.I.-John Thompson and Morgan Crucible—has established graphite machining facilities in the old Royal Ordnance Factory at Sopers Lane, Waterloo, near Poole. The machine shop, which occupies some 65,000 sq ft, first went into operation towards the end of last year.

Morgan Crucible have, of course, a great deal of experience of machining graphite and the detailed design of the shop was handled by the company's industrial engineering department. An accompanying drawing shows the layout of the shop floor and the relative positions of tools.

Nuclear Graphite has, in fact, three main production lines: one for bricks, one for tiles and a central line for the provision of features in either bricks or tiles or for the production of reflector shapes. Here again, the installation is very flexible: there is sufficient room between production lines for machines to be moved if necessary. Adjacent machines are linked by roller conveyors. Ball tables assist the operator during loading or unloading operations.

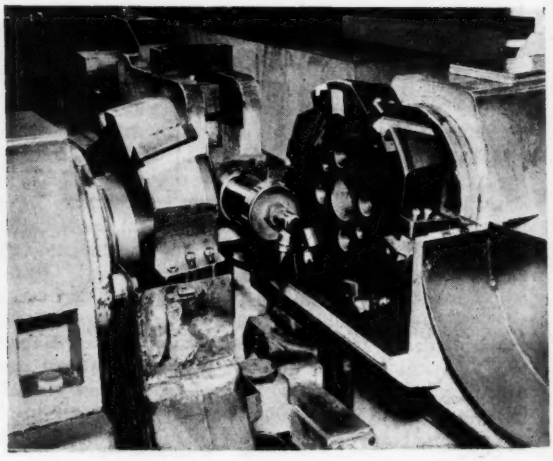
The Berkeley moderator bricks present an unusual machining problem because slots are required in the fuel channel bore to contain support struts for the elements. These slots are obtained by broaching, each block being subjected to four passes to complete the operation.

So far as the brick machining line is concerned the raw blocks are hydraulically loaded on to the machine table. A simple air-operated jig is used for bandsawing. The feed is automatic and an autoset device operates every two strokes. The procedure is to trim one side of the billet and then roll it over and trim the other side at right angles, using one table of the machine. This process is repeated at operation 2, using the other side of the table. To balance the line there are four bandsaws.

Next, the ends are sawn so that the overall length is reduced to 30.65 in. Reduction of the brick outer faces to final size is obtained by milling two sides simultaneously on a duplex miller. The brick is held in a simple jig. A strip change in the base of the machine enables changes in size of brick to be accommodated without difficulty. When all four side faces have been milled, the

(Below) Berkeley moderator bricks are first trimmed on a bandsaw; they are held in position by an air-operated clamp.

(Below) Sintox hard ceramic tools offer considerable possibilities for graphite cutting. These cutters are shown here being tested by Nuclear Graphite.



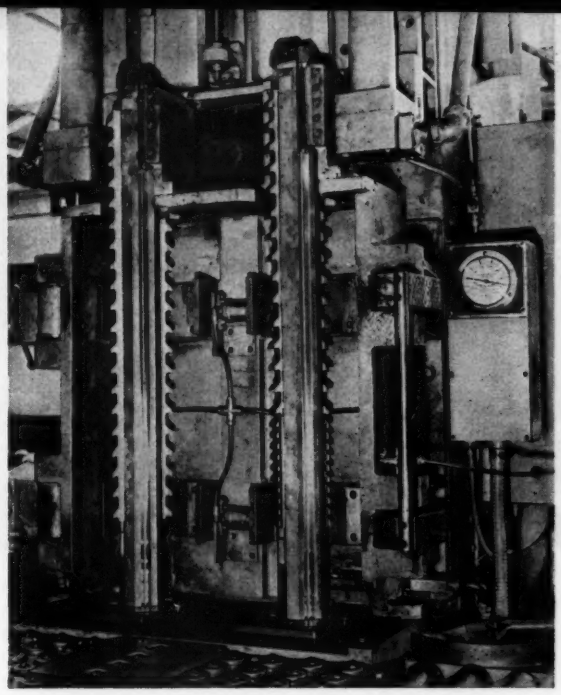
end face is machined to ensure that it is flat and square for the boring and broaching operations. The end face is also marked with a dimple hole so that the datum corner can be accurately located subsequently.

The boring operation is carried out in two stages on vertical machines supplied by Archdale's. Two borers are used in turn, one roughing, the other finishing. In the roughing operation a $3\frac{1}{4}$ in. diameter bore takes 1 min 20 sec: approximately 25 lb of material are removed during this stage. From the finish boring operation the brick is passed to the broach, the two slots in the bore requiring four separate passes. The broach is pulled through the bore of the brick which is held in position by a clamp. End features are now generated by four-spindle and two-spindle mills, the required angle of the feature being controlled by strips in the base of the machine. Finally, a fillet radius is milled by a single H.S.S. cutter. 25% of the Berkeley bricks have this feature.

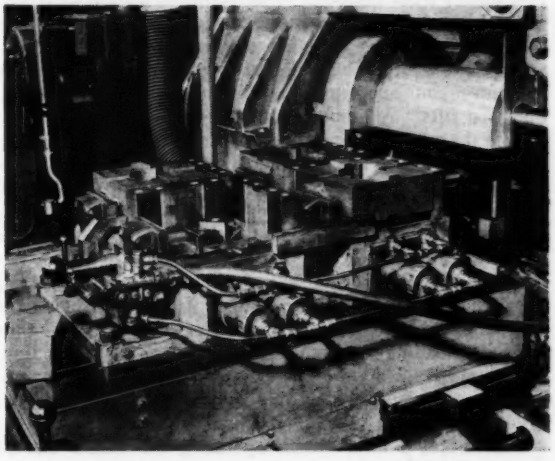
The completed brick is now given a thorough final check on a Sigma equipment arranged to check 58 dimensions simultaneously. The Sigma unit is used not only as a gauge but also as a quality control tool as the last readings can be retained for comparison. By centralizing inspection in this way delays on the line can be considerably reduced. The most critical operation (end features) is, of course, adjacent to the gauge.

The Berkeley tile line is designed to make either thick or thin tiles, the jigs for each type being rapidly interchangeable according to requirements. The block, 8-in. square by 30-in. long, is first bandsawn to billet size either making four thin billets $8\frac{3}{16}$-in. long or three thick billets 11-in. long. In the next two operations two faces of the billets are milled at right angles, the first two on a three-spindle unit and then on a two-spindle horizontal and vertical mill. These operations are necessary so that the faces are true for the boring and broaching stages which follow. The bored and broached billets are now sawn into the appropriate thickness of tile before being passed to air-clamped jigs for keys and keyways to be milled.

The jigs are so arranged that the tiles can be inserted in the correct position only. Great care is taken on the tile line to ensure concentricity of the bore to the end face and parallelism of end faces to minimize the possibility of gas leaks in the pile.

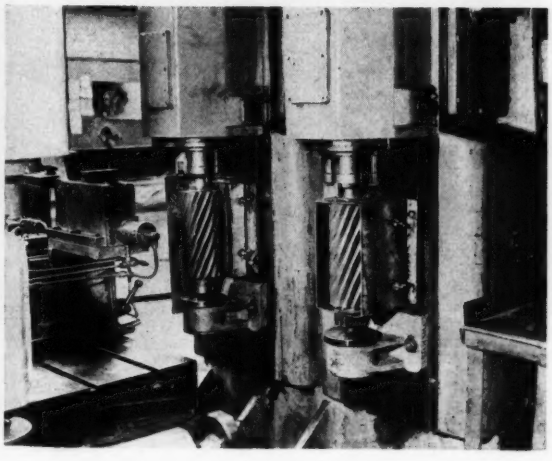


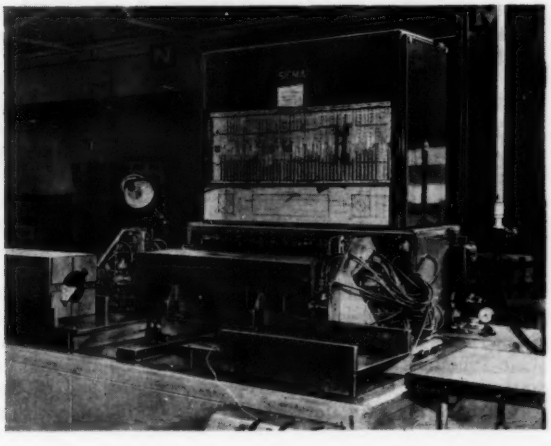
One of two twin broaching machines, purpose-made by Archdale's for cutting slots in the Berkeley moderator bricks.

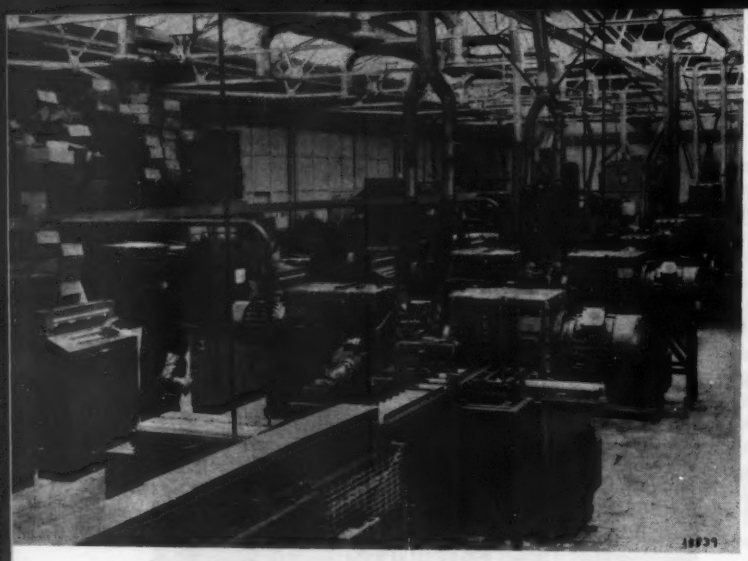


(Above) Berkeley tiles being milled to final thickness. The fixture is air-operated. (Below) Sigma gauging equipment at the end of Nuclear Graphites moderator machining line. Fifty-eight dimensions can be measured simultaneously.

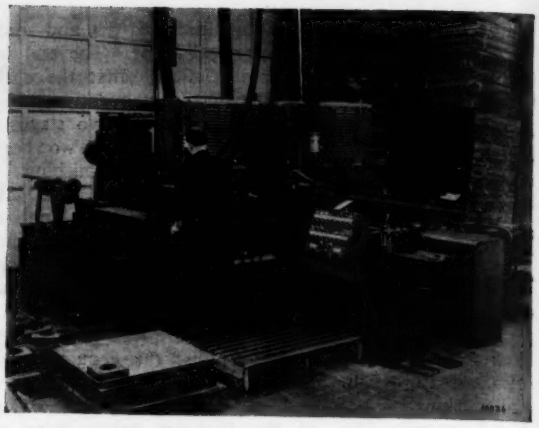
(Below) Twin spindles on one side of a duplex mill. The cutting heads can be quickly interchanged for different end features.







Automatic brick transfer line in the Reyrolle shop. General view of line from station 1 where the first two parallel sides of bricks are milled.



Automatic transfer line for tiles. On a four-station loading table tiles have keys and keyways generated; they are also reduced to finished thickness.

A. Reyrolle

Machining facilities for the Bradwell blocks are conveniently located in a new building adjacent to Anglo Great Lakes' graphite factory at Newburn Haugh. The installation differs from the other three shops in a significant way —blocks and tiles are handled by an automatic transfer line.

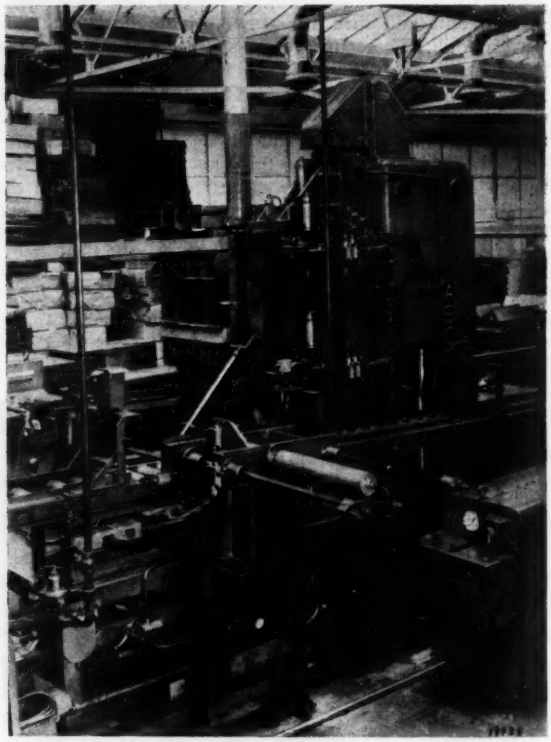
The moderator block transfer line comprises five machines connected by gravity run conveyors and air-operated lifts. All movements are electrically interlocked so that the whole line can be operated from a single station. Provision is made for each machine to be separately controlled for tool-setting. The line starts with a Wadkin circular saw which trims the edges from the raw block.

When a component leaves the saw the operator loads it onto a gravity run conveyor which takes it to an air-operated lift at the beginning of the transfer line. The lift rises when the first machine finishes its cycle, bringing the component up to a gravity feed roller track where it rolls onto the loading station. The component strikes a limit switch which lowers the air-operated lift for the next component and operates a loading ram taking the component into the fixture. The loading ram, at the end of its forward stroke strikes a limit switch operating the fixture clamps and then returns to its starting position. Only when these functions have taken place will the spindle motors start and the fixture commence to feed forward. At the end of the forward stroke of the fixture the spindle motors stop, the fixture clamps release and the unloading ram pushes the component on to the unloading station. When the unloading ram has returned to its starting position, the fixture returns to the loading point.

If there is no component in the loading station of the following machine and the end of cycle on the boring machine has been signalled, the component is indexed through 90° and rolled down to the second machine hitting a limit switch which returns the off loader on the first machine to its original position.

The component now in the second machine operates a limit switch which replaces the off loader on the first machine and operates the loading ram, pushing the component into the fixture. The loading ram at the end of its forward stroke strikes a limit switch operating the fixture clamps and then returns to its starting position. When these functions have been completed the spindle motors start and the fixture traverse begins. At the end of the forward traverse the spindle motors stop and the fixture clamps are released. The fixture clamps actuate a limit switch which operates the unloading ram pushing the component on to the unloading station. When the unloading ram returns to its starting position the fixture then traverses back to the loading position.

The component runs down the track to the third machine, a vertical borer, to a stop and strikes a limit switch which lowers the off loader on the previous machine and operates the loading ram taking the component on to the loading platform for the fixture. At the end of the



Station 3 on the brick transfer line is the vertical borer. The whole of the Reyrolle transfer installation was carried out by Asquith Machine Tool Corporation.

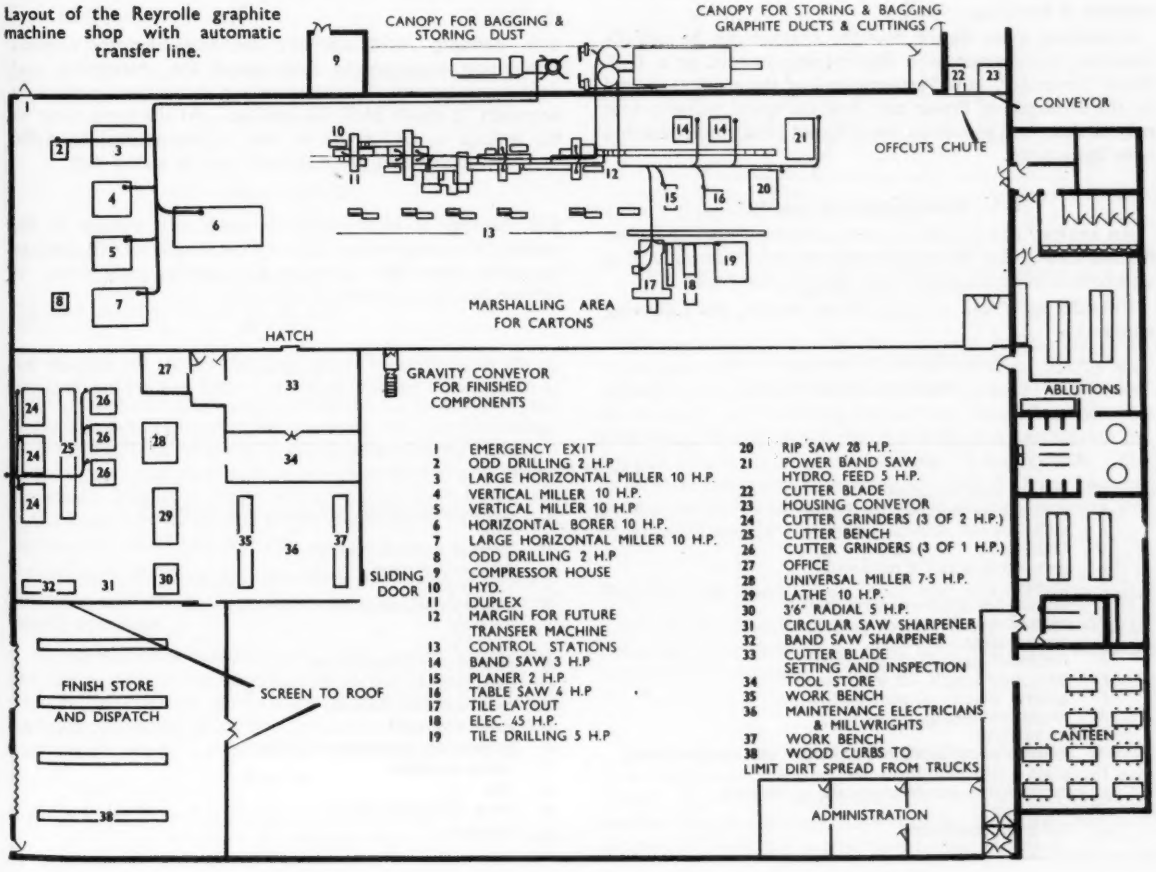
loading ram stroke a limit switch is depressed which operates the plaform clamps; the clamps going on signals the loading ram to return to its starting position. The platform then swings the component up and into the boring fixture; the platform clamps are released, the component being held by a latch on the fixture, and the fixture clamps are applied. The boring bar motor starts and the fixture slide traverses down and boring commences. At the end of the boring cycle with the fixture back in the starting position the boring bar motor stops and the fixture clamps release. The fixture clamps releasing apply the platform clamps and the platform swings the component back on to the loading position. At the same time the stop on the conveyor track is lowered. The platform clamps are released and the unloading ram moves forward sliding the component back on to the roller track and the component runs down the track to the next machine. At the loading station of the next machine the component strikes a limit switch which raises the stop in the track and returns the unloading ram.

From the boring machine the component passes to the loading station of the fourth machine, a double duplex miller. The loading ram pushes the component into the fixture and the fixture clamps are applied. The loading ram returning to the starting position starts the spindle motors and the fixture feeds through the cutters. At the end of the feeding stroke the fixture clamps release and the unloading ram pushes the component on to the unloader, which indexes the component through 90°, and the fixture then traverses back to the loading position. The component then runs down the conveyor track to the fifth machine, a duplex miller. Here, it strikes a limit switch which returns the off loader on the fourth machine and operates the loading ram thus taking the component into the fixture. The fixture clamps are applied and the loading ram returns to the starting point thus starting the spindle motors and the fixture commences to feed forward through the cutters. At the end of the feeding stroke the fixture clamps are removed and the unloading ram moves forward taking the component on to the conveyor track; then it returns to the starting point; the fixture will then traverse back to the loading position. The component runs down the unloading conveyor and momentarily operates a limit switch which signals that the component is clear.

The most interesting feature of the tile line is an automatic four-station machine with stages for loading and unloading, milling keys and keyways and reducing the thickness to finished size.

Final inspection of moderator bricks for Bradwell. Simple jigs and gauges are used for this purpose.

Layout of the Reyrolle graphite machine shop with automatic transfer line.


CANOPY FOR BAGGING & STORING DUST
CANOPY FOR STORING & BAGGING GRAPHITE DUCTS & CUTTINGS
CONVEYOR
OFFCUTS CHUTE
MARSHALLING AREA FOR CARTONS
HATCH
GRAVITY CONVEYOR FOR FINISHED COMPONENTS
SLIDING DOOR
ABLUTIONS
FINISH STORE AND DISPATCH
SCREEN TO ROOF
CANTEEN
ADMINISTRATION
1 EMERGENCY EXIT
2 ODD DRILLING 2 H.P
3 LARGE HORIZONTAL MILLER 10 H.P.
4 VERTICAL MILLER 10 H.P.
5 VERTICAL MILLER 10 H.P
6 HORIZONTAL BORER 10 H.P.
7 LARGE HORIZONTAL MILLER 10 H.P.
8 ODD DRILLING 2 H.P
9 COMPRESSOR HOUSE
10 HYD.
11 DUPLEX
12 MARGIN FOR FUTURE TRANSFER MACHINE
13 CONTROL STATIONS
14 BAND SAW 3 H.P
15 PLANER 2 H.P
16 TABLE SAW 4 H.P
17 TILE LAYOUT
18 ELEC. 45 H.P.
19 TILE DRILLING 5 H.P
20 RIP SAW 28 H.P.
21 POWER BAND SAW HYDRO. FEED 5 H.P.
22 CUTTER BLADE
23 HOUSING CONVEYOR
24 CUTTER GRINDERS (3 OF 2 H.P.)
25 CUTTER BENCH
26 CUTTER GRINDERS (3 OF 1 H.P.)
27 OFFICE
28 UNIVERSAL MILLER 7·5 H.P.
29 LATHE 10 H.P.
30 3'6" RADIAL 5 H.P.
31 CIRCULAR SAW SHARPENER
32 BAND SAW SHARPENER
33 CUTTER BLADE SETTING AND INSPECTION
34 TOOL STORE
35 WORK BENCH
36 MAINTENANCE ELECTRICIANS & MILLWRIGHTS
37 WORK BENCH
38 WOOD CURBS TO LIMIT DIRT SPREAD FROM TRUCKS

REACTOR PHYSICS

for the Electrical Engineer

Part II.

By J. C. JAMES, M.A.
(*CEGB. R. and D. Department*)

In Part I, published in the April issue, the author indicated the close parallelism of the fundamental quantities of reactor physics with electrical science. In Part II, below, this study is extended to the basic functional characteristics of the complete reactor circuit as compared with an electrical circuit.

THE first part of this article gave a brief review of neutron kinetics using the concepts of neutron flux and neutron current. The analogy between these and electrical potential and current was pointed out, based on the similarity of Fick's and Ohm's laws. The electrical theory, if not already familiar, is at least a well proven presentation of ideas and it is worthwhile extending the analogy. It was shown that a clear account of the significant reactor parameters (leakage, critical size, etc.) could be given in terms of Resistance and Natural Unit of Length, so avoiding the less straightforward concept of Buckling.

It remains to be shown how the analogy can be usefully extended, the reactor as a whole being likened to a D.C. Shunt Generator, how Perturbations of the reactor depend on the analogue of Power and how the transient behaviour may be described by comparing Delayed Neutron Production with Inductance.

D.C. Shunt Generator Analogy

An analogy can be said to exist between a nuclear fission reactor and a d.c. shunt generator mainly because each is an example of an amplifier with positive feed-back.

Considering a unit volume of the reactor, the following applies :—

$$\text{total neutron production} = \Sigma_a k \phi$$
$$\text{neutron absorption} = \Sigma_a \phi$$

Thus

$$\text{net neutron production} = \Sigma_a (k-1)\phi = \Sigma_a \Delta k \phi$$

Taking into account[3] the leakage current $= -\frac{\lambda}{3}\nabla^2\phi$

Criticality is expressed by $D\nabla^2\phi - \Sigma_a \Delta k \phi = 0$.

It can further be stated that the net neutron production

$$\Sigma_a \Delta k \phi = \phi \Delta k / R_a$$

or, say

$$= \phi / R_g$$

thus defining resistances R_a corresponding to neutron production necessary to make good the absorption, and defining resistances R_g corresponding to neutron production necessary to make good the leakage. At the same time, as the leakage is $D\nabla^2\phi$ and as this is proportional to ϕ for variation in flux at a given point, it can be stated that

$$\Sigma_a \Delta k \phi = \phi / R_f$$

The quantity R_f is the same for each unit volume in the reactor (if homogeneous) since the core material will produce the same proportion of excess neutrons at each point. It follows that for the state of criticality

$$R_g = R_f \quad . \quad . \quad . \quad . \quad (19)$$

i.e. the production of excess neutrons equals the leakage but an independent neutron source is needed to start the reaction.

List of Symbols

C	isotope concentration	S	signal
D	distance or position—or Drag	s	standard deviation—or absorption resistance
f	suffix for fast neutron group	t	time
G	Gain	V	average neutron velocity
g	generating negative resistance	v	neutron velocity
I	current	x	variable
i	current variation—or term marker	Y	characteristic generation resistance
J	current density	y	variable
j	term marker	z	variable
k	constant—reproduction constant	Σ	sum of—or cross-section
L	particular length—or inductance	δ	perturbation or finite change sign
l	general length—or neutron lifetime	Λ	extrapolation distance
M	migration length	λ	mean free path
m	mean value	β	proportion of delayed neutrons
N	number of collisions in particular—or neutron density	τ	decay constant
P	pitch	ϕ	flux
p	probability—resonance escape probability	Δ	finite difference sign
R	resistance	ϱ	reactivity
r	diffusion resistance		

Now turning to the electrical analogy, a circuit diagram illustrating an equivalent d.c. shunt generator arrangement is shown in Fig. 7a. The machine produces a current

in the load circuit $I_a=\phi/R_a$

and in the field circuit $I_f=\phi/R_f$

and a voltage in the armature circuit $\phi=I_fR_g$

which, R_g being a transfer impedance, represents the production of the magnetic field and its induction of a voltage into the armature windings. These two conditions only hold, if

$$R_g=R_f \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

which is analogous to equation 19. Similarly a residual magnetic field is required before voltage will build up, but fortunately saturation of the field iron avoids the need of " control rods " as in a reactor, i.e. for a given field resistance the voltage is stable.

Sub-Critical Amplification

In the sub-critical condition, the d.c. shunt generator will amplify any signal current S in parallel with the armature, for both circuits. Thus, we have

$$S+\phi/R_g=I_f=\phi/R_f$$

$$S=\phi(R_g-R_f)/R_gR_f$$

and the gain is

$$G=I_f/S=R_g/(R_g-R_f)$$

This condition is shown in Fig. 7b. A like condition obtains for reactors where the signal S represents a source of neutron current and the same equation can be written in terms of δk as follows :—

For small variations from criticality

when $k_1=1+\Delta_1k$ (before variation)

and $k_2=1+\Delta_2k$ (after variation)

Then

$$R_{g1}=R_{f1}$$

$$=R_a/\Delta_1k$$

and $R_{g2}=R_a/\Delta_2k$

and the gain

$$G=\Delta_1k/(\Delta_1k-\Delta_2k)=\Delta_1k/\delta k \quad . \quad . \quad . \quad . \quad . \quad (21)$$

The gain becomes infinite for $\delta k=0$.

Reactivity

Just as in Part I there were introduced the terms Pitch and Natural Length corresponding to active and passive media, so in the analogue of power it is convenient to use " Drive " and " Drag " corresponding to power generated and power absorbed. These are related to the neutron flux and current in the same way as electric power is related to voltage and current, i.e. $W=VI$ or $W=I^2R$.

Dealing with Drag first the laws applicable to electric networks may be used to derive an important feature of reactor operation.

Taking the paths between the neutron current streamlines, and the equivalent resistances as branches of an (electrical) network, the currents of which obey Fick's (Ohm's) Law and applying circulation (Kirchhoff's) Laws to the network it can be stated for the branch circuits in any or all the meshes

$$\Sigma IR=0$$

and the Drag (power absorbed) in the network

$$D_1=\Sigma I^2R \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

If now a change occurs in a mesh current so that Fick's (Ohm's) Law no longer obtains, then

$$D_2=\underset{\text{in mesh}}{\Sigma(I+i)^2R}+\underset{\text{in rest of network}}{\Sigma I^2R}$$

$$=\underset{\text{in all network}}{\Sigma I^2R}+\underset{\text{in mesh}}{\Sigma 2IiR}+\underset{\text{in mesh}}{\Sigma i^2R}$$

$$=\underset{\text{in all network}}{\Sigma I^2R}+\underset{\text{in mesh}}{2i\Sigma IR}+\underset{\text{in mesh}}{\Sigma i^2R}$$

But ΣIR is zero for a mesh without source,

therefore

$$D_2=\underset{\text{in network}}{\Sigma I^2R}+\underset{\text{in mesh}}{i^2\Sigma R}$$

It follows that D_2 is always greater than D_1, i.e. for a given set of source currents the distribution in accordance with Fick's (Ohm's) Law makes ΣI^2R a minimum.

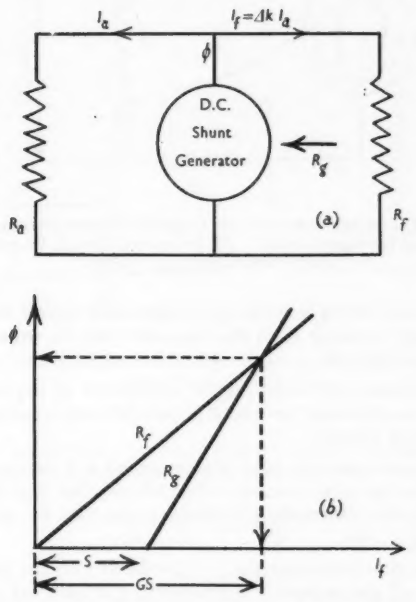


Fig. 7.—(a) Circuit Diagram of Shunt Generator Analogy. (b) Reactor Gain Diagram indicating amplification of a fixed neutron source S.

In an electrical network the equation $\Sigma I^2R=\Sigma\phi I$ is an expression of the Principle of Conservation of Energy and although this equation may be deduced in both the electrical and nuclear cases from the circuit laws, the analogy between Fick's and Ohm's Laws is taken as sufficient justification for the use of the equation here in the nuclear system. The term ϕI is conveniently referred to as the " Drive " corresponding to the power generated in an electrical network and equation 22 may be stated as

$$\text{DRIVE}=\text{DRAG} \quad . \quad . \quad . \quad . \quad . \quad (23)$$

The units are (neutrons/cm, sec)^2 and correspond to watts.

It is in fact possible to base reactor theory on the ideas of Drive and Drag deriving the other parameters from them, as shown in the appendix.

Perturbations

Perturbations are special variations in the reactor steady-state conditions, changes of Drag or Drive in one part (which would be compensated by opposing changes in another part) producing distortions of the initial flux and current but avoiding a continuous time variation.

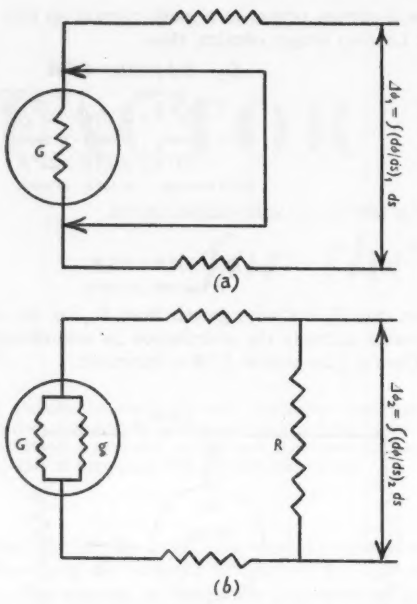


Fig. 8.—(a) Equivalent Circuit Diagram of reactor—unperturbed or "open circuit." (b) Equivalent Circuit Diagram of reactor—perturbed or "loaded."

If any one of the resistors in the equivalent circuit diagram be altered, a change δk in the value of k will be required to maintain criticality.

The change in the value may be represented by the connection of an additional resistor R in parallel with some part of the existing network.

The reactor network may be represented as a two-terminal network comprising a source and a resistor. (See Figs. 8a and 8b.) The flux difference is the same across both the arrowed lines in Fig. (8a).

If new non-fissile material is introduced into the reactor, one end of the resistor S representing this material is connected to the sink where $\phi=0$. The potential across which the resistor is connected, is ϕ_1.

After the connection and the compensating δk have been made, the flux pattern changes and the potential is now ϕ_2. This action is analogous to the fall in voltage resulting from the loading of an electrical system.

The current absorbed is

$$I=\phi_2/S$$

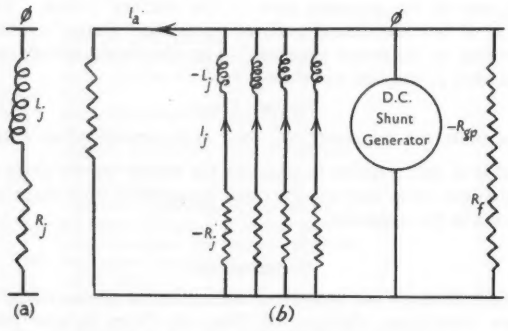


Fig. 9.—(a) Equivalent Circuit Diagram of one delayed neutron group. (b) Equivalent Circuit Diagram of reactor incorporating several delayed neutron groups.

The additional drive provided by the source is

$$D=\phi_1 I=\phi_1\phi_2/S$$

or the integral of this in the case of extended material.

But the additional drive may be written by the same method as

$$D\int_{\text{Core}} \phi_A\phi_B/R_g=\int \phi_A\phi_B k/R_a$$

Hence

$$\delta k=\frac{\int \phi_1\phi_2/S}{\int_{\text{Core}} \phi_A\phi_B/R_a} \quad \ldots\ldots\ldots\ldots \quad (24)$$

If the quantity of new material introduced is small, then

$$\phi_1\simeq\phi_2 \text{ and } \phi_A\simeq\phi_B$$

so that

$$\delta k=\frac{\text{Additional Drag of New Material}}{\text{Original Drive of Core}} \quad . \quad (25)$$

Reactor Kinetics

If the effective reproduction constant k should exceed unity, the reactor flux and current will vary in time, increasing in the ratio k in the average time between the release of a neutron and its fission absorption. The situation is complicated by the fact that a proportion of the neutrons are released by the radioactive decay products of fission and there are at least six such products (or precursors) with half-lives of up to a minute which together provide a proportion $\beta=0.75\%$ of the neutrons produced. These neutrons provide a delayed current, produce a delayed flux and cause delayed Drive analogous to inductance in electrical circuits.

The rate of increase of C_j, the concentration of the precursor of the jth group of delayed neutrons equals the rate of formation less the rate of decay.

The rate of formation is expressed by

$$\frac{dC_j}{dt}=\frac{k}{p}\beta_j\Sigma_a\phi-\frac{C_j}{\tau_j} \quad \text{per unit volume}$$

where p is the resonance escape probability, and the neutron current deriving from the decay is expressed by

$$\frac{C_j}{\tau_j}=I_j$$

$$\frac{\tau_j dI_j}{dt}+I_j=\frac{k}{p}\beta_j\Sigma_a$$

or

$$\frac{pI_j}{k\beta_j\Sigma_a}+\frac{p\tau_j}{k\beta_j\Sigma_a}\cdot\frac{dI_j}{dt}=\phi$$

or

$$R_jI_j+\frac{L_j dI_j}{dt}=\phi \quad \ldots\ldots\ldots \quad (26)$$

Turning once more to electrical analogy, this represents at the same time the differential equation for an electrical circuit of the resistance $R_j=p/k\ \beta_j\Sigma_a$ in series with an inductance $L_j=p\tau_j/k\ \beta_j\Sigma_a$ as shown in Fig. 9a.

Each group of delayed neutrons can be represented by a shunt circuit in parallel with the armature, with R_g adjusted to R_p (to represent only prompt neutrons). Thus many of the characteristics of a reactor can be represented by Fig. 9b.

In the steady-state, the inductances play no part and the resistances

R_j and R_p in parallel $=R_g=R_f$.

In this condition the reactor may be considered sub-critical by a reactivity $\beta=\delta k/k$ and amplifying the delayed neutron current so that from equation 21

$$G_1=\Delta_1 k/\beta k=\varrho_1/\beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

and the leakage current

$$I_{f1}=G_1 I_d=I_d\varrho_1/\beta$$

and the flux

$$\phi_1=I_{f1}R_f=G_1 I_{d1}R_f$$

For a small positive change $\delta\varrho$ the reactor may now be considered sub-critical by $\beta-\delta\varrho$ and the gain changes to

$$G_2=\varrho_1/(\beta-\delta\varrho) \quad . \quad . \quad . \quad . \quad (28)$$

and the leakage current becomes

$$I_{f2}=G_2 I_{d1}$$

hence the flux becomes

$$\phi_2=G_2 I_{d1}R_f$$

and the ratio

$$\phi_2/\phi_1=G_2/G_1=\beta/(\beta-\delta\varrho) \quad . \quad . \quad (29)$$

The transition from ϕ_1 to ϕ_2 (see Fig. 10) takes place exponentially (since the rate of increase of I_d and thus ϕ is proportional to ϕ) and is rapid. The time constant involved may be shown to be

$$T_p=l/(\beta-\delta\varrho)$$

where l is the neutron life time.

Following the rapid increase of the flux, I_d begins to grow in response. There is a transition period involving a multi-term exponential while the delayed neutron group currents adjust themselves to the new conditions. Eventually a single exponential predominates.

If, however, a potential

$$\phi=\phi_0 \exp(t/T)$$

be applied to an inductance L across which

$$\phi=L\mathrm{d}I/\mathrm{d}t$$

then $$I=T \exp(t/T)/L$$

and $$\phi/I=L/T=\text{constant}$$

i.e. it is not possible from a record of the potential and current to tell whether an inductance L or a resistance L/T is connected.

Under the above conditions, the resistance of the delayed neutron shunt circuits appears to be

$$R=R_j+L_j/T$$

Throughout the latter period the amplification is

$$I_f/I_d=G_2 \quad \text{and} \quad \phi=I_{f2}R_f=G_2 I_d R_f$$

Equating the leakage current to the excess generated current under the new conditions of gain

$$\frac{\phi}{R_f}=I_f=G_2 I_d=\frac{G_2\phi}{\Sigma.1/(R_j+L_jT)}$$

This is equivalent to equating the positive leakage resistance to the negative generating resistance.

But under steady-state conditions

$$\frac{\phi}{R_f}=\frac{G_1\phi}{\Sigma.1/R_j}$$

Hence

$$1/(R_j+L_j/T)=(G_2/G_1)\Sigma 1/R_j=(\beta/(\beta-\delta\varrho))1/R_j$$

This equation enables one to determine the time constant T, so as to maintain the balance between the positive and negative resistances. It is readily solved for $\delta\varrho$ for a given T but not vice versa except graphically.

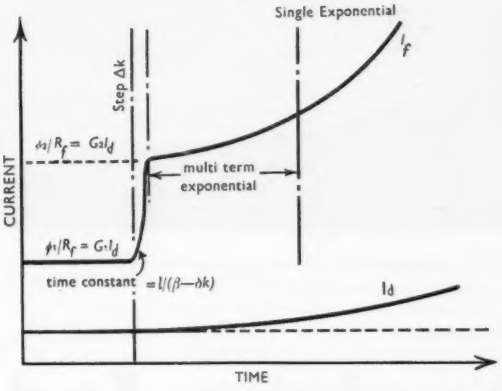


Fig. 10.—Delayed and leakage currents following positive step change of reactivity.

But if there were only one group of delayed neutrons with a time constant of τ sec the solution would be

$$T=\frac{L}{G_1R_f}\cdot\frac{\beta-\delta\varrho}{\delta\varrho}=\tau\frac{\beta-\delta\varrho}{\delta\varrho} \quad . \quad . \quad . \quad . \quad . \quad (30)$$

As long as $\delta\varrho=\beta$ and is positive, $G_2/G_1=\infty$. For greater values the system is super-critical on prompt neutrons alone and the flux continues to increase exponentially with a time constant of the order of $l/(\delta\varrho-\beta)$.

For negative steps the equation $G_2/G_1=\beta/(\beta-\delta\varrho)$ obtains, the values of $\delta\varrho$ now being negative. In that case, after the initial rapid fall, the flux continues to decrease at a rate determined by the delayed neutron half-lives. There is no effect corresponding to equation 30.

The author is grateful to the Central Electricity Generating Board for the opportunity to study the above and allied subjects at A.E.R.E., Harwell; also to the Atomic Energy Authority and their staff for valuable assistance, freely given.

For References See Part I (April Issue).

La Physique Nucléaire pour l'Ingenieur-Electricien

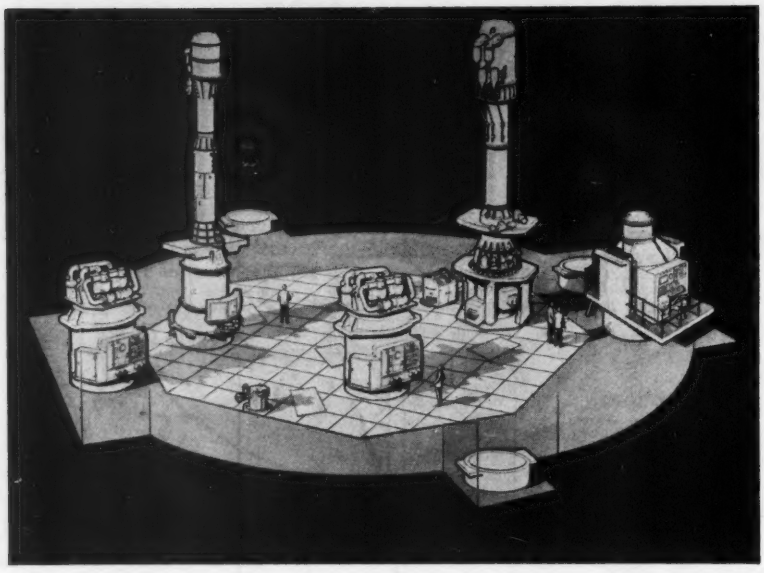
La partie actuelle, qui est la dernière, traite d'analogies particulières entre des systèmes de réacteurs entiers comparés à des circuits électriques entiers. On fait voir que les principes d'opération du réacteur à fission nucléaire peuvent être comparés au principe opérationnel du générateur shunt de courant continu, car l'un et l'autre représentent un exemple de l'amplificateur à réaction positive.

Atomphysik für den Elektro-Ingenieur

Der vorliegende den Aufsatz abschliessende Teil behandelt die spezielle Analogie zwischen ganzen Reaktor-Systemen im Vergleich zu ganzen elektrischen Stromkreisen. Es wird gezeigt, dass im Grunde der Betrieb eines Kernspaltungs-Reaktors dem Betrieb eines Gleichstrom-Nebenschluss-Generators gleichgesetzt werden kann, da beide ein Beispiel der Verstärkung mit positiver Rück-Kottlung darstellen.

Fisica Nuclear para el Ingeniero Eléctrico

Esta parte (la segunda y final) trata de las analogias especificas entre sistemas completos de reactor comparados con circuitos eléctricos completos. Se muestra que los principios de funcionamiento del reactor de fisión nuclear pueden ser asemejados al principio de funcionamiento del generador en " shunt " de C.C., ya que cualquiera de ellos representa un ejemplo del amplificador con reacción positiva.



A diagram of the fuel charge and discharge machinery for the Berkeley power station being built by A.E.I.—John Thompson.

The emphasis is on nuclear engineering at The* 1959 *Engineering, Marine, Welding and Nuclear Energy Exhibition (Olympia, London, April* 16 *to* 30*). This hall-by-hall report discusses those stands of especial interest to the nuclear industry.

Nuclear Industry on Show

GRAND HALL

A part of the **John Thompson** stand (4F, ground, Grand) is devoted to a display of the fuel loading and unloading machinery for Berkeley power station. One item of the plant is a 27 ft section of the 50 ft high fuel chute showing how the pressure vessel contains the top portion of a 3-channel rotatable magazine and winding gear with two wire cables supporting the chute lifting grab. Outside the top section there is a differential gear box which ensures that the chute's main cable carries 10 times the load of the secondary, or emergency, cable. The display is shown in relation to the reactor face at Berkeley. The flux scanning winches are also displayed in this manner.

Babcock and Wilcox have devoted a prominent section of their display to sectional models of a reactor group and steam-raising unit illustrating their part in the construction of the Hinkley Point power station. This, along with a variety of components for nuclear power generation and research and a section touching on the progress in nuclear ship propulsion, makes an impressive exhibit. (3G, ground, Grand.)

Tufnol is a material possessing excellent electrical insulating properties. On stand 3K, ground, Grand, can be seen panels for instruments and control boards, insulating nuts, bolts, screws and bushings, moulded insulators and terminal boards in this material.

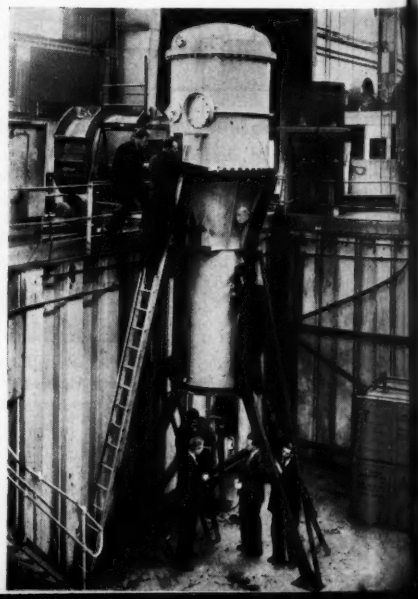
Products for air filtration which includes electric-cell and adjustable cast fan systems are shown by **Air Control Installations.** (27, outer gallery, Grand.)

Main theme of the **Accles and Pollock** stand is precision tubes—including a standpipe head made for Hunterston power station. The head contains the stainless steel burst cartridge detection tubes which pass through the wall of the pressure vessel standpipe to a rotary selector valve. Of considerable interest is the company's display of extruded cans in Magnox, tubes in niobium, vanadium, tantalum, zirconium and titanium and its alloys. Of a more general interest are tubes with extremely thin walls in stainless steels and other metals and convoluted flexible tubing and bellows made from seamless thin-wall tubes. (50, inner gallery, Grand.)

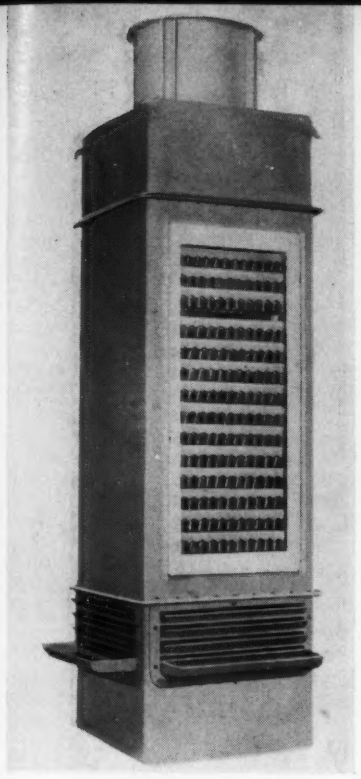
A Savage and Parsons master slave manipulator, illustrating the use of Kanigen plated aluminium components, is on view at the **Albright and Wilson** stand (3, outer gallery, Grand). Kanigen is also extensively used to combat corrosion caused by uranium hexafluoride.

For grouping burst slug detection pipes in nuclear power stations, the **Richard Klinger** 8 unit sleeve-packed cock manifold can be seen on 1C, ground, Grand.

C. A. Parsons (5E, ground, Grand) display a model of a 100 MW turbo-generator with steam conditions suitable for a nuclear station. The generator is of the normal hydrogen cooled design using a rotor of the direct gas-cooled type. There is also a sectional model of a graphite-moderated gas-cooled reactor. The model shows the graphite moderator in full with charge pans above and gives a clear indication of the flow circuits.



A 27-ft. section of a chute machine for the Berkeley power station by John Thompson.



Film Cooling Towers' induced draught cooling tower.

Film Cooling Towers (36, inner row gallery, Grand) have a small induced draught cooling tower as their main exhibit. The cooling tower is made of polyester resin bonded glass-fibre with a Perspex access panel so that the film flow grid packing can be seen in operation.

Operating with nearly complete absence of vibration, **Consolidated Pneumatic Tool** class FE compressors (6C, ground, Grand) are horizontal, double acting, balanced, opposed units which, by means of altering the sizes of cylinders, or increasing the number of crank throws, can be supplied for compressed air at 40 lb/sq in. or for industrial purposes requiring up to 3,000 lbs/sq in. Capacities of up to 5,000 cu ft/min are available.

On the **Midland Industries** stand (46, inner gallery, Grand) is an entirely new float trap incorporating an air vent that has been designed to withstand conditions where superheated steam is present.

An electric governor for the accurate control of prime movers for a.c. generating sets where any alteration in frequency under varying load conditions must be kept to a minimum is featured by **Ardleigh Engineering** (42, outer gallery, Grand).

A control rod standpipe produced for the Hunterston nuclear power station by **Stewarts and Lloyds** can be seen on stand 4E, ground, Grand, where the emphasis is on manipulated pipework.

The Dolphin floating suction strainer with a combination plastic and stainless-steel construction to combat corrosion can be seen on the **Megator Pumps and Compressor** stand. (9C, ground, Grand.)

On show at the **B. A. Holland Engineering** stand at 5B, ground, Grand, are compressors, vacuum pumps and exhausters. This company are supplying four Holland/SLM rotary exhausters to Berkeley power station. The exhausters are powered by a motor of 65 b.h.p. at a speed of 485 r.p.m. Suction capacity at 95% vacuum is 1,120 c.f.m.

For quantitative and qualitative chemical analysis of compounds containing elements in the range uranium (92) to titanium (22), **Metropolitan-Vickers** (10E, ground, Grand) are showing an X-ray microanalyser.

British Oxygen have two stands. On 5G, ground, Grand, they are showing the latest developments for the storage and supply of liquid oxygen in vacuum-insulated vessels and on 1W, Empire, there is a one-tenth scale model of a port and starboard computer-controlled gas cutting machine.

Amongst the chemicals shown by the **Distillers Company** is a special feature displaying use of CO_2 for the cooling of nuclear reactors (9D, ground, Grand).

Mono Pumps feature a complete range of pumps for handling free-flowing, viscous or abrasive fluids (28, inner row gallery, Grand).

A static display of pneumatic valves and cylinders together with a closed circuit film showing applications of this equipment forms part of the **Westinghouse Brake and Signal** exhibit (F15, ground, Grand).

Sharples Centrifuges who are developing centrifuge equipment for highly active materials, have on display one of their smaller models of super-centrifuges. (5D, ground, Grand.)

Another piece of equipment being supplied to a nuclear power plant is the **Reyrolle** control-rod head which is for the Bradwell power station. (6E, ground, Grand.) A dummy stand-pipe rig has been arranged to show in action the raising and lowering equipment which is driven from a synchronous motor in the head. The motors, which are capable of extremely low rotational speeds, require a special power supply from a low-frequency generator set. The stand also includes a gas-sampling selector valve which automatically and continuously selects the hot circulating gases from a number of fuel channels and passes them on to a monitoring system where the amount of radioactivity is recorded on chart recorders.

Steam condensers and heat exchanger tube plates, up to the largest sizes, are shown by **Yorkshire Imperial Metals.** The wide range of alloys includes bi-metal plates in combinations of steel and stainless steel clad on one or both sides with non-ferrous alloys. (11G, ground, Grand.)

Beldam Asbestos (3D, ground, Grand) display a range of jointings, packings, filters and mechanical rubber products, among which is the Kymbala-type of jointings for superheated steam.

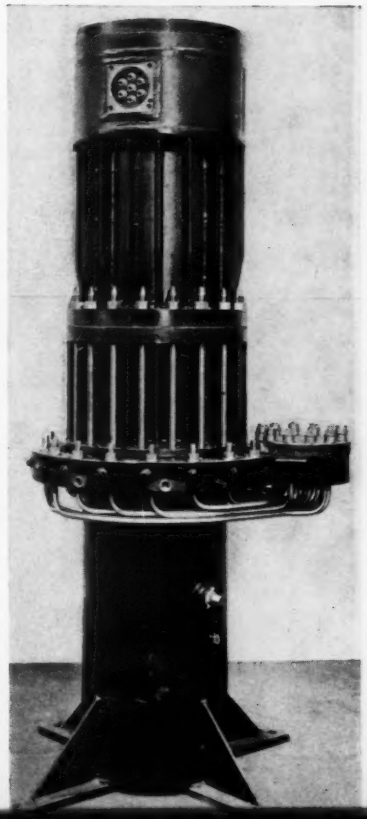
Fan engineering equipment and industrial gas apparatus which includes a 70-in. AR impeller with backward-bladed aerofoil section blades, providing efficiencies of up to 90%, can be seen on the **Keith Blackman** stand. (1A, ground, Grand.)

A 3,000-ton vertical press capable of bending 3-in. plate is shown by **Hugh Smith** (17A, ground, Grand). This press can be used for the fabrication of reactor and heat exchanger casings.

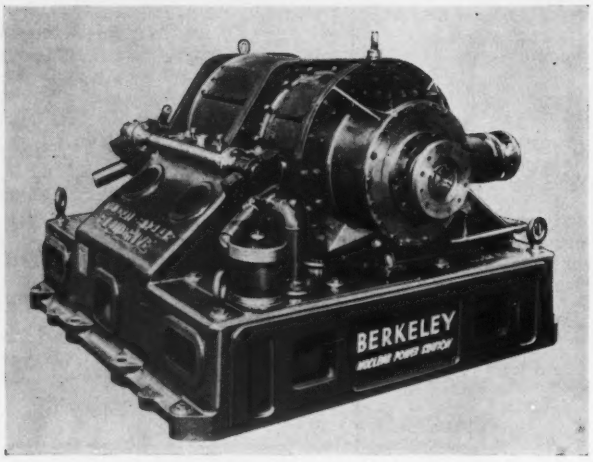
Leak-proof air and fluid hose couplings with a ball-locking device, only recently made available to the British market, can be seen on the stand of **Guyson Industrial Equipment** (5, inner gallery, Grand).

Valves and fittings specifically designed for the nuclear industry are included in **Newman, Hender's** stand (9J, ground, Grand).

Among the continental exhibitors are **Pleuger** of Hamburg who make submersible pumps for reactor cooling systems. Pleuger pumps are installed at the CERN institute in Geneva. U.K. representatives are **British Pleuger Submersible Pumps** (31, outer gallery, Grand).



The Reyrolle control-rod head for Bradwell.



Vulcan-Sinclair double-circuit fluid coupling for Berkeley.

An interesting exhibit is the Vulcan-Sinclair double-circuit scoop-trim fluid coupling, 16 of which are to be included in the 3,000 h.p. axial blower drives at the Berkeley power station. This DST type of fluid coupling is marketed in five sizes, ranging from size 20, which transmits 3,000 h.p. at 3,000 r.p.m., to size 30, rated at 20,000 h.p. at 3,000 r.p.m. **Fluidrive Engineering** (4H, ground, Grand).

The importance of new developments in tube design for installations where maximum heat transfer is necessary is well illustrated on the **Tubes** stand (9A, ground, Grand). Of special interest among the ranges of cold-drawn seamless, special polished, honed and centreless and cold reduced seamless steel tubes, are ranges of superheater and heat-exchanger tubes and steam pipes. These are supplied plain or manipulated to meet requirements.

Valves suited for nuclear applications are amongst the exhibit of steam traps, steam reducers and general steam plant of **I. V. Pressure Controllers.** (38, inner gallery, Grand.)

Pumps and compressors having application in all fields of engineering form the main part of the **Hamworthy Engineering** exhibition. (14F, ground, Grand.)

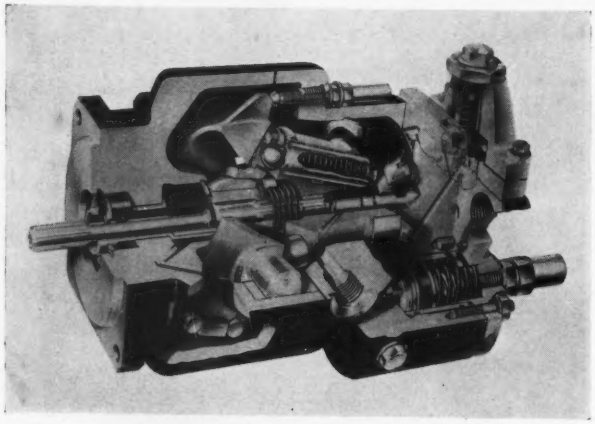
Examples of suction air filters as installed at several nuclear power stations can be seen on stand 46, outer gallery, Grand, where **New Welbeck** are showing air-cleaning equipment. This concern has designed special units for handling radioactive materials.

Protective clothing, compressed-air breathing apparatus and portable welding and cutting apparatus, can be seen on the **Siebe, Gorman** stand at 9K, ground, Grand.

The Metastream flexible metallic power transmission couplings, similar to those installed on pumps at Calder Hall, are on show at **Metaducts** stand (27, inner gallery, Grand). The couplings are of metal construction and are non-lubricated.

Centrifugal and horizontal compressors are of interest on the **Harland and Wolff** (5F, and 4G, ground, Grand) exhibit. The company make compressors suitable for pressures of up to 15,000 p.s.i.g. and absorbing up to 6,000 b.h.p.

Metalock have a casting illustrating their method of key or stitch repair of a fracture. Portable equipment for the Furmanite method of sealing steam leaks under pressure can also be seen. (44, outer gallery, Grand.)



Joseph Lucas are showing a disc-type hydraulic pump. (7a, ground, Grand.)

Of the five **I.C.I.** divisions, **Metals** have a most interesting display of materials for nuclear engineering (28, outer gallery, Grand). Wrought metals such as zirconium, titanium, niobium and vanadium and fuel cans and Integron extended surface boiler tubes are all on display, together with burst-cartridge detection gear and fabricated products for nuclear engineering. A section dealing with heat-transfer products includes typical aluminium alloy and titanium heat exchangers.

Amongst their range of heat exchangers, **Serck** have an A type with a hydrostatic fan drive; this unit is illustrated by an $\frac{1}{8}$-in. scale model. This type of exchanger has a low centre of gravity with low resistance to prevailing winds. The tube bundles can be removed without disturbing the framework or supporting structure. (8G, ground, Grand.)

Precision Rubbers (10, outer gallery, Grand) are showing high-temperature grades of Prescolastik silicone rubber and Viton, for fuel and acid resistance of up to 300° C.

Langley Alloys produce a series of alloys resistant to corrosion. These can be seen on stand 9H, ground, Grand, in various forms including castings, bar and forgings. Valves, including a new Y-type, are also on display.

Included in their selection of industrial blowers, vacuum pumps, gas boosters and superchargers, **Sir George Godfrey** (13, inner gallery, Grand) features a series of butterfly valves capable of adaptation for nuclear engineering applications.

Lubricators for introducing lubricant into compressed air supplied to air cylinders, air tools, etc., can be seen on the **Shipston Engineering** stand (38, outer gallery, Grand). Ranging from $\frac{1}{4}$ in. to 1 in., these micro-fog lubricators operate by means of a variable vane in the air supply giving them a minimum operating flow of 5 c.f.m. regardless of pipe size.

Spun iron pipes, reinforced concrete pipes and prestressed concrete pressure pipes, together with flexible joints, are on the **Stanton Ironworks** stand. (13J, ground, Grand.)

Glacier Metal's display is one of bearings, including spherical journal, anti-whirl turbine, dry bearing materials and reticular aluminium-tin alloy. The dry bearing materials are reputed to be capable of operating quite satisfactorily at temperatures ranging from −200°C to 327°C (41, inner gallery, Grand).

Two new fluid seals, Hallprene 110, a fluoro silicone rubber for use with solvents at temperatures from −60°C to 200°C, and Hallprene 130, a fluorocarbon polymer Viton A rubber for use with oils, solvents, chemicals and acids at temperatures up to 250°C, are among the **Hall and Hall** exhibits. (4J, ground, Grand.)

Several types of forced lubrication pumps are being shown by **Drysdale** (7H, ground, Grand).

Of special interest on the **Wakefield-Dick** stand (12, inner gallery, Grand) is the company's Nucleol range of radiation-resistant lubricants.

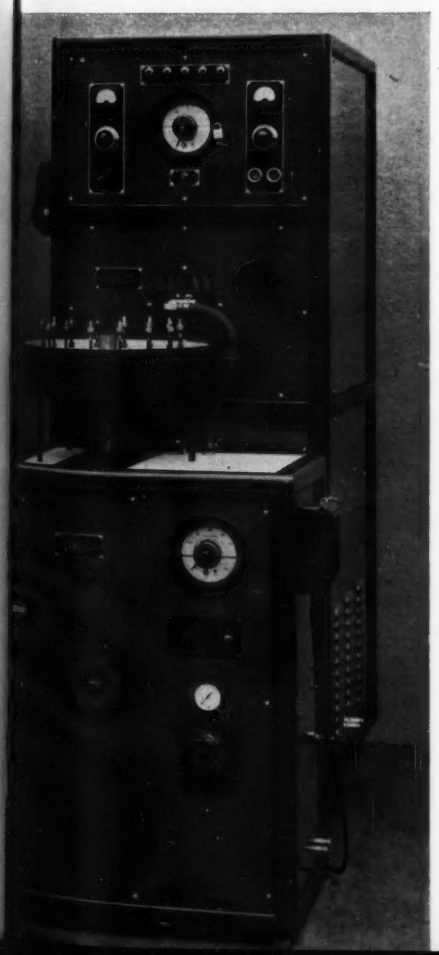
A newly designed laboratory dryer for producing extreme dryness in gases required for nuclear and metallurgical applications is shown by the **Dryer and Gas Plant** division of **Birlec** (13E, ground, Grand). The dryer can make use of various desiccants with molecular sieve adsorbent. Birlec also feature one of their standard atmosphere generators fitted to a continuous furnace for annealing and brazing.

Vapour pressure thermometers of the distant reading and rigid stem vapour pressure type from 2½ in. to 8 in. dial sizes, temperature controllers and pressure recorders, are all included on the **British Rototherm** stand (14, inner gallery, Grand).

Sperry Gyroscope's exhibit deals with nuclear reactor control and industrial control engineering (9F, ground, Grand). Two of the exhibits comprise a fine position indicator for control rods and a design of a complete reactor control rod winding mechanism.

Plannair show an extensive range of axial flow and centrifugal blowers on 23, inner gallery, Grand. A 5-in. axial flow combined blower/heater with an output of 170 c.f.m. is shown in operation on a pressurized assembly cabinet made by John Bass of Crawley.

Standard Telephone and Cables' induction heating generator of continuous 1kw output (12F, ground, Grand).



Angular contact ball bearing built by Cooper Roller Bearings.

A protective cream for decontaminating protective clothing is shown by **Rozalex** (26, inner gallery, Grand).

Electric current distribution systems and a wide range of bearings, both lined and unlined, are of interest on the **Anti-Attrition Metal** stand (35, outer gallery, Grand).

Castings in a wide range of Paralloy stainless, heat resisting, carbon and special alloy steels form part of the **A.P.V. Paramount** display. The company produces steel compositions to meet demands made by the nuclear industry. Also shown are guide pans and lanterns for nuclear power plants. (12K, ground, Grand.)

Resin-bonded dispersions of PTFE manufactured by **Acheson Colloids** and marketed under the trade mark, Emralon, are on stand 32, outer gallery, Grand. Advantages of the coatings are extremely low coefficient of friction, good stability at high temperatures and high resistance to chemical attack.

Mond Nickel (2G, ground, Grand) are demonstrating the creep-resistance of platinum metals, sub-zero properties, integral sheath thermocouples and apparatus for testing the corrosion-resistance of materials under thermal load.

Corrosion-resistant chemicals, comprising phosphate treatments, derusting, cold brush-on and spray treatments and chemical oxidation processes are exhibited on stand 18, outer gallery, Grand. The **Walterisation** cold extrusion method of manufacture is also shown.

Ruston and Hornsby and their associates, **Davey, Paxman,** have a joint display this year and for the first time will be showing a product developed for the nuclear industry. This is the NFB gas bearing circulator designed for circulating gas at high temperatures and pressure without leakage. The rotating assembly of the circulator is carried on bearings which use pumped gas, air, carbon dioxide or helium as bearing fluids. Water-cooled and air-cooled diesel engines of the latest design are also on display (9E, ground, Grand).

NATIONAL HALL

An outstanding display concerns a 90 in. angular contact ball bearing rotated by a tiny electric motor. Built by **Cooper Roller Bearings,** two of these bearings will be supplied to the Berkeley power station. They will support the control rod and actuator servicing machine for the reactors and each will carry loads of 90 tons. The bearings, the largest made so far by the company, are 100 in. O.D. by 8½ in. deep. The lower bearing race has an integral 398-teeth gear ring and each bearing contains 116 2½ in. balls. A force of only 7 ounces applied at the race periphery is sufficient to start and maintain motion (4M, ground, National).

British LaBour Pump show two new pumps on stand 3P, ground, National. One is the type DSZ direct mounting horizontal centrifugal pump and the other the MSZ horizontal floated suction centrifugal single stage process pump. Construction of the DSZ has been simplified by coupling the pump directly to the driving motor and eliminating the bearing bracket which results in a considerable shortening of the pump.

Nylon sealing washers, known as Selons, are new products shown by **Dowty Seals** (7, centre gallery, National). They are captive and self-centralizing and are an economic replacement for copper, copper asbestos and fibre washers.

Of interest to nuclear power station constructors is the exhibit of open steel flooring and stair threads, tubular handrailing and handrail standards as shown by **Bettles** on stand 1P, ground, National.

Butters Bros. derricks have been widely used in the construction of nuclear power stations and models and photographs of these at work can be seen at 2L, ground, National.

One of the few firms with research exhibits are **Napiers** who feature research into titanium welding. This company have seven years of experience in the joining and fabrication of titanium based materials (2R, ground, National). Napier shaft seals have been specified for CO_2 main gas duct circulators.

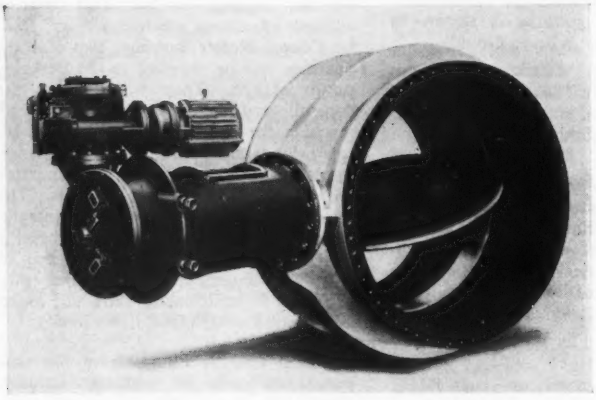
Opperman Gears on stand 4Q, ground, National, are exhibiting a new range of speed reducers of the co-axial helical and spur type of up to 60 h.p.

On the **Blakeborough and Sons** stand (8N, ground, National) there is a selection of fluid control valves for both nuclear and conventional power stations. Most outstanding is a 60-in. bore motor-operated butterfly valve as supplied for main gas duct service. It is of the stressed seal type, the construction allowing a relative expansion between valve disc and body and at the same time enabling a positive seal to be applied in the shut position. Examples of bellows sealed gate and globe valves for radioactive gas conditions on secondary CO_2 circuits and an 8-in. bore reactor charge and discharge valve, are also on view.

Darlington Insulation, who are at present insulating the heat exchangers at Bradwell, have played a major part in the insulation of nuclear power plants in the U.K. Photographs and specimens of the company's work can be inspected on the **Darlington Group** stand at 5L, ground, National.

For power station service **Aiton** feature a selection of pipes on stand 3M, ground, National. There are pipes in stainless steel for supercritical pressure service, in chromium/molybdenum and chromium/molybdenum alloy steel and in carbon steel for high-pressure boiler units.

Allspeeds, who have supplied a substantial number of their standard speed variators to the AEA, have a new vertical unit on their stand (3, inner gallery, National).



Blakeborough's 60-in. bore motor-operated butterfly valve.

Gamma radiographic equipment for non-destructive testing is shown by **Nuclear Engineering,** a division of **G. A. Harvey** (6M, ground, National.)

A subsidiary of **United Steel, Distington Engineering,** manufacture coffins for the disposal of radioactive waste materials (6P, ground, National).

Automatic voltage regulators, suitable for 60-cycle generators, high-frequency generators capable of electrical output of 1.5 KVA at 110 volts when running at 2,400 r.p.m. and high speed gearbox and geared motor units form part of an interesting display on 6N, ground, National, **British Thomson-Houston.**

Plessiflex is used in many nuclear applications, but probably the most important is for the remote handling of fuel elements. Plessiflex has been used with a small-diameter television camera that is lowered into a reactor to watch the fuel element charge and discharge operation. Plessiflex can form a connection from stack-pipe valves to burst slug-detection pipes. The hose, which can be supplied in materials such as niobium and zirconium, is shown by **Power Auxiliaries** on 9, centre gallery, National.

A material known as Devcon L, which is 90% lead and 10% plastic, is shown by **E. P. Barrus** (18, outer gallery, National).

To illustrate the advantages of quick response and voltage stability as well as mechanical merits, the **G.E.C.** Accurex static excitation unit is shown controlling an alternator. The exhibit is arranged so that a number of motors can be started direct to line. (3L, ground, National.)

Audco lubricated taper plug valves, both manually and power operated, are shown in a variety of sizes ranging from ¼ in. to 24 in. bore on the **Audley Engineering** exhibit (7P, ground, National).

A double beat diaphragm valve that has already undergone tests on a nuclear power station, is among the valves, controllers and surface-type desuperheaters shown by **British Arca Regulators** (11S, ground, National).

A stand with the emphasis on hydraulic and pneumatic control is 1S, ground, National, with a member of the **Turner** group, **Hydraulics and Pneumatics,** showing automatic variable delivery piston pumps, selector valves and hand pumps among other pressure hydraulic components.

A recently introduced Mk. 2 range of air cylinders suitable for air and low-pressure hydraulic applications is amongst the air cylinder and control valve exhibit of **Maxam Power** (20, outer, National).

Included in their selection of pneumatic cylinders and control valves, **Martonair** (24, outer gallery, National) have a new impact cylinder. The one-ton/in. capacity model of this range is suitable for delivering a maximum blow of 20 tons. It is capable of punching a 1-in. diameter hole in an ¼-in.-thick mild-steel plate at 80 p.s.i. air supply. Up to 30 blows per minute can be delivered.

The **English Electric** stand (6Q, ground, National) contains a scale model of the 500 MW nuclear power station being built at Hinkley Point.

Forms of thermal and sound insulation including extra high temperature material, by **Newalls Insulation,** and asbestos reinforced plastics in sheets, rods and tubes, machined parts and mouldings by **J. W. Roberts,** both members of the **Turner and Newall** organization, are on stand 8DD, first, Empire.

Hunt and Mitton offer a wide range of control valves of their own manufacture. The company also represents Francel of Paris (19, outer gallery, National).

Worthington-Simpson (4S, ground, National) show centrifugal and steam pumps, rotary and air compressors and ejector and extraction pumps. The maximum capacity of pumps exhibited is 3,900 g.p.m. with heads of up to 600 ft.

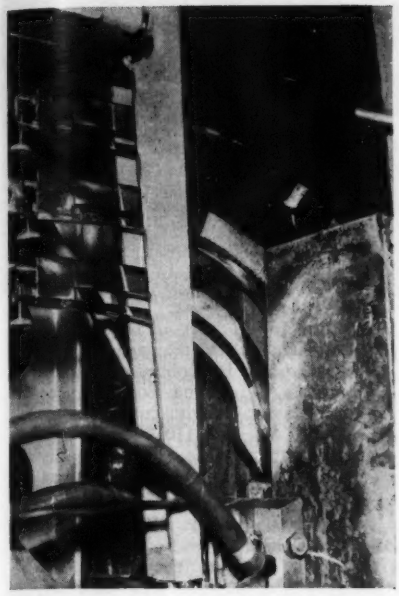
Brooks and Walker feature valve products in cast steel, stainless steel, cast iron and gunmetal with working pressures from 100 to 600 p.s.i. (3, outer gallery, National). Pressure and vacuum gauges, flush and flange mountings and sight-flow glasses in stainless steel, gunmetal and cast iron are also to be seen.

Hobson at 7, outer gallery, National, have an outstanding display of nuclear components. They have been major suppliers of reactor controls and nuclear ancillary equipment to the AEA for some time. Prominent among the exhibits are gearboxes for master-slave manipulators, fine and safety control systems for reactors; the honeycomb isotope unit designed for isotope irradiation and the Hobson-C.R.L. master-slave manipulator for the remote handling of radioactive or toxic materials.

An air pressure regulator by **Schrader** evens out the line pressure to the actual requirements at any point and keeps the pressure constant at that point. By simple screw adjustment inlet pressures of up to 250 p.s.i.g. can be regulated down to a range of 5-125 p.s.i.g. (16, inner gallery, National).

Stratton manufacture variable capacitors which are available in different sizes, types and vane spacings. (1A, outer gallery, National.)

Stein Atkinson Vickers Hydraulics (9M, ground, National) include a new series of high-performance, vane type pumps, operating at 2,000 p.s.i., in their exhibit.



Vertomatic vertical slag-welding machine built by Rockweld, shown with three electrodes in position and suitable for thicknesses up to 15 in. For 3 in. metal one electrode only is used.

EMPIRE HALL

New equipment shown by **Hirst Electronic** (3X, ground, Empire) includes a resistance welding current meter with six ranges covering readings from 500 to 100,000 amps, 25 and 60 KVA heavy-duty resistance spot welders, and a welder for plastics-coated sheet metal.

Sintox, an impervious alumina ware, is shown by **Lodge** on stand 3AA, first, Empire. With its low neutron capture cross-section, hardness, good electrical and mechanical properties at high temperatures, Sintox has many applications in the nuclear field.

One of the most comprehensive displays of welding equipment is by **Lincoln Electric** on stand 4U, ground, Empire. To illustrate their interest in nuclear engineering they have included the L.R.C. travelling boom with revolving column, shown in conjunction with a Lincolnweld B.10 fully automatic submerged arc-welding head, and Lincoln L.S.A.R. self-aligning rotators to demonstrate the automatic circumferential welding of heavy steel vessels.

An entirely new automatic vertical slag-welding machine, called the Vertomatic, is being introduced by **Rockweld** (2U, ground, Empire). The machine is now being manufactured to patents held by Vus (Bratislavia) for which Rockweld are the sole licensees in the U.K. The equipment provides for considerable economies in the welding of heavy fabrications in plate thicknesses of 2 in. and upwards. This is achieved by the minimization of plate preparation, the elimination of multiple passes with associated deslagging and chipping, economy in flux powders and the high thermal efficiency of the process which results in low energy consumption. In a demonstration of the machine a 2-in. weld, 2 ft long, was completed in 40 min. Rate of deposition is some 50 lb/h per electrode. Rockweld are also showing the Autopak arc-welding equipment which is now boom-mounted with a self-propelled carriage.

Illustrating their part in the nuclear field **Mobil** have a large photograph of Hinkley Point power station for which the company has a lubrication contract. (12DD, first, Empire.)

Deloro Stellite (3W, ground, Empire) have introduced a mechanized equipment unit for protecting components against wear, heat and corrosion by the Stellite process—spraying with a metal powder spray which is then fused to the base metal. The process is automatic and produces a thin smooth deposit on cylindrical components. The spray-fuse unit consists of a powered carriage running on rollers and carrying a spray gun and fusing torch in tandem.

A new heavy-duty rotator of 75 tons capacity designed for welding boilers, pressure vessels and heat exchangers is shown by **Yates Plant** (7W and 9V, ground, Empire). A feature of the unit is the inclusion of self-propelling roll carriages which adjust the roll spacing for different diameter vessels by means of normal controls. Another feature is a creep control device which corrects endwise movement of vessels during welding.

Cape Asbestos are showing a colour sound film of their mines in South Africa (13AA, first, Empire). The company has several nuclear insulation contracts in hand.

An example of aluminium welded by inert-gas-shielded methods is on the **British Aluminium** stand at 1CC, first, Empire. A new welding gun enables thinner material to be welded.

Among the several **Murex** welding exhibits (2W, ground, Empire) is the Muramatic—an automatic welding head and control unit. The head can be mounted on a single or double-headed deckwelder carried on booms, columns, mobile platforms and so on. It has been designed for use with the submerged-arc or open-arc process using either A.C. or D.C. supply and with welding currents up to 1,200 amp.

Typical examples of the application of aluminium in nuclear engineering are on **Northern Aluminium's** stand at 7BB, first, Empire. Uses for aluminium include sections from cyclotron windings, fuel element cans, valves, pipework, panelling and framework, fuel element sandwich plates, gaseous diffusion equipment and busbars.

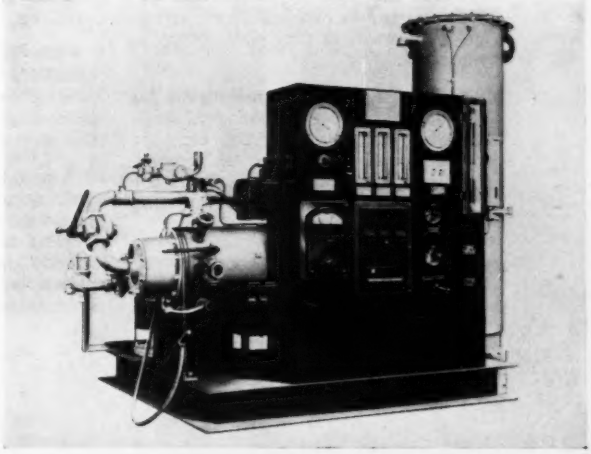
Twiflex Couplings, who have supplied couplings for several nuclear stations, including the Dounreay fast breeder, are displaying their full range of products on 5EE, first, Empire.

Talbot Stead Tube have made nuclear engineering the main theme of their stand. Products for the industry include pressure vessels, breeder thermocouple guide tubes, fuel element support and restraint bar and charge plugs. In addition there are scale models of control rod, restraint bar and charging standpipe assemblies (9AA, first, Empire).

A flash butt welder, suitable for welding aluminium, is of interest on the **Electro Mechan-Heat** stand. (4Y, ground, Empire.)

A **Holmes** inert gas generator, producing inert gas to any specification by the controlled combustion of fuel gas or fuel oil, can be seen on stand 6DD, first, Empire. Dryers, multi-wash systems, multi-cell cyclone dust collectors, electric air filters and positive air-blowers are also on display.

Lincoln B.10 fully automatic submerged arc-welding head.

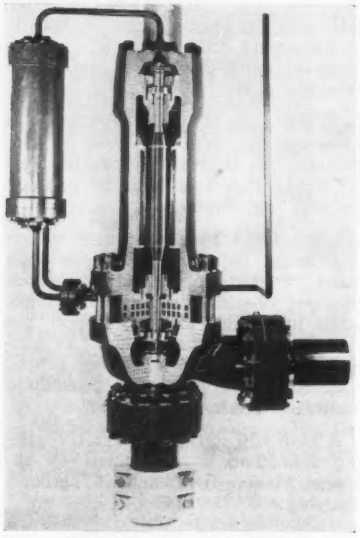


Holmes inert gas generator.

Quasi-Arc (5W, ground, Empire) have seven new developments for show this year including Unionmelt multi-power welding which is now being used on all of the nuclear power stations under construction. This process will be illustrated by a static display showing the nose of a high-lift welding boom similar to the one supplied for use at Hunterston.

Goodyear Pumps, a member of the **Holman Group** are showing on stand 4DD, first, Empire, a complete range of products which feature a positive-displacement rubber-to-metal self-priming pump.

The **K.S.B. Manufacturing** company, who represent the German manufacturers **K.S.B. Export,** feature an Amag valve, developed for nuclear power stations on their stand (6BB, first, Empire). The unit comprises a bellows-type gland backed by a normal gland to provide additional safety; there is a connection for a leak detector.

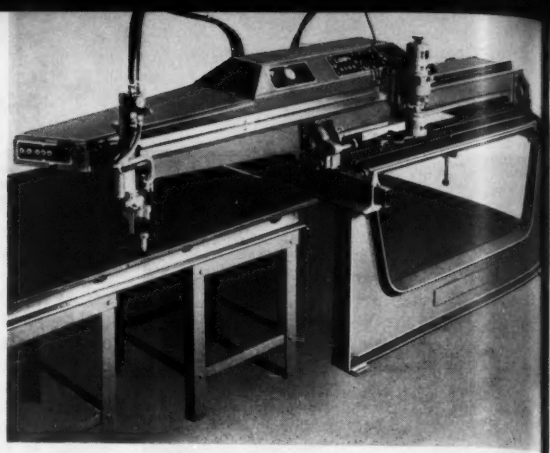


K.S.B. glandless circulating pump.

The new **Marconi** 300 kV constant potential X-ray apparatus, comprising a tubeshield and oil-cooler, twin h.t. generator tanks and a control unit, is on stand 3DD, first, Empire. Mountings range from a static type of tube stand to overhead telescopic suspension. The unit is suitable for the examination of castings and seam welds in steel plates of up to 4-in. thick.

Welding rectifiers, designed mainly for the tungsten inert gas welding of stainless steel, nimonic, titanium, etc., are to be found on stand 7X, ground, Empire. These oil-cooled units, made by **Arc Manufacturing,** have capacities from 40 to 250 amps.

A. and S. Osmond show a representative range of their cutting-off machines on stand 12AA, first, Empire.



Hancoline oxygen profile-cutting machine.

Welding equipment that includes large seam and multi-spot units, as well as small bench types, is shown by **British Federal Welder and Machine** (2Y, ground, Empire).

Fourteen of **F. Bode and Son's** 60 different welding positioning machines are on stand 8X, ground, Empire. Some of the machines are on show for the first time.

A heavy-duty gunmetal fullway valve is of some note on the **Robert Harrow** stand (11AA, first, Empire). The valve is a heavy-duty type with the spindle rising through a non-rising handwheel. It is made of sand-cast gunmetal in sizes from 1 to 3 in. and has screwed and flanged connections to B.S.S.

An impressive demonstration of an automatic mechanical shotblast machine for descaling all types of sectional steel lengths and steel plate is being given by **Tilghman** (5Y, ground, Empire).

Italian ball and roller bearings manufactured by **Riv** of Turin and marketed in the U.K. by **Revolvo** are on stand 1EE, first, Empire. The bearings are ball, spherical roller, cylindrical roller and taper roller types in inch and metric sizes.

The Gasfluxer automatic fluxing process of **Weldcraft** is demonstrated on stands 6W and 6X, ground, Empire. The process eliminates hand fluxing in bronze welding entirely and produces residue-free welds.

A demonstration of variable speed drive gears is being given by **Carter Gears** (10AA, first, Empire). A drive, consisting of an electric motor, F type variable speed gear and worm reduction gear, is operated by a simple cam arrangement designed to effect a typical cycle of speed variation.

Fuller Electric feature an automatically controlled flash welder designed for welding tubular elements with internal automatic flash removal and upset reduction device. (6V, ground, Empire.)

A portable spot-welding gun for direct welding of aluminium down to 2 by 16 s.w.g., and a new hand portable arc-welding transformer for use on either 200/250 or 400/440-volt mains are displayed on the **Portable Welders** stand. (4Z ground, Empire.)

An automatic electronic oxygen profiling machine, the Hancoline, is featured by **Hancocks** (6X, ground, Empire). The machine is available with cutting widths of 40, 62, 80 and 120 inch and is equipped with a roller drive. It automatically compensates for width of cut.

An unusual exhibit is the **Myford Mini-Kop** hydraulic copying lathe (11DD, first, Empire). The machine has a swing-over cross-slide, 4-in. diameter, maximum turning length of 14 in., with alternate approach angles. The copy slide is hydraulic, and so is the carriage traverse. The company is also showing the MG12 cylindrical grinding machine with a 5-in. swing capacity and 12 in. between centres.

Intermit (8BB, first, Empire), a company making filters and strainers, show compressed air filters, air and liquid controls as well as air filtration and air-conditioning products.

Vacu-Blast are showing four of their range of mobile dust-free shot-blast machines on stand 6W, ground, Empire. The machines incorporate closed circuit pressure-vacuum systems for the supply of abrasive to the work surface with arrangements for the recovery of spent abrasive, dust and debris.

Vacu-Blast method of cleaning a large internal surface.

NEW BOOKS

British Instruments. Directory and Buyers' Guide, 1959. (322 pp. + 293 pp. Manufacturers' Announcements.) Scientific Instrument Manufacturers' Association (Sima) and United Science Press, Ltd. 42s.

The 1959 Directory and Buyers' Guide is indeed justly claimed to represent a major achievement. The Directory is not restricted to members of Sima and the 2,500 distinct individual headings of its Classified Index of Products impressively demonstrate the capacity and widespread activities of British Instrument Industry as a whole.

The book is well planned and the promoters of this venture have obviously seen to it that many of the minor sins of omission, so irritating to potential buyers who seek information, in particular to those living in places remote from well-organized commercial centres, should not be committed this time. For example, the alphabetical list of manufacturers shows all branches and agencies of a firm the world over, complete with full address. Further, a Glossary section is incorporated giving a condensed index of the classified list of products in French, German and Spanish. Here, in fact, the non-English-speaking buyer is at a slight advantage over the English-speaking buyer, since glossaries of this kind are of proven convenience in tracing information. It would add to the value of the book, if an English glossary were inserted in future issues.

Besides the three sections already mentioned, there are another five, not counting Manufacturers' Announcements. The first gives a brief précis of the 11 associations allied to the Instrument Industry, and co-operating in the promotion of the Directory. The second lists relevant British Standard Specifications and the third, the names and addresses of individuals and companies known as consultants in instrument technology. Finally, the last two form a register of firms prepared to deal with prototypes and the development of instruments to customers' order, and a record of trade names respectively. Both appear to be somewhat short and incomplete, and can be expected to be longer in subsequent editions.

Constitutional Diagrams of Uranium and Thorium Alloys. By R. A. Rough and A. A. Bower. (153 pp.) Addison-Wesley Publishing Co., Inc., 1958. (London office: 10-15 Chitty Street, W.1. Trade distributor for the sterling area: Book Centre, Ltd.) $5.

This book is a revised and up-to-date version of the original Battelle Memorial Institute publication, BMI-1000, on Uranium and Thorium Alloy Diagrams. Sixty-five binary Uranium alloys are reviewed and 44 Thorium binary systems, together with several ternary systems. The authors have drawn on published information from unclassified and classified sources, including much work that has not been generally available hitherto. Each system is described in terms of its constitutional diagrams, where sufficient information is available, and the authors point out the regions where the evidence is conflicting, briefly discussing the discrepancies, and the methods used by the various investigators. Where serious conflict arises in the evidence, a tentative diagram is given with the authors' comments on its probable form. Wherever possible the crystal structure of each intermetallic phase is tabulated, together with the dimensions of the unit cell, the density of the compound, its space group and remarks on its morphology. A bibliography is given with each system.

In all, the authors have made an excellent job of presentation which, whilst of necessity being brief and to the point, adequately covers the groundwork in a field in which the information is sometimes sketchy, often conflicting and invariably incomplete. The systems which are of most importance for nuclear reactor compatibility studies have been described in greater detail than others, since these are the systems which have been investigated most thoroughly. Although no attempt has been made to discuss compatibility, kinetics or thermodynamics, which are obviously outside the scope of the present volume, the work will serve as an invaluable reference for all interested in these fields of research.

A.J.M.

Special Relativity for Physicists. By G. Stephenson and C. W. Kilmister. (108 pp., Longmans Green and Co., Ltd., 1958.) 18s. net.

In modern physics there is a whole range of phenomena, the explanation of which is based on the theory of special relativity. It has therefore become essential for students of physics to have a thorough understanding of this subject. Existing books tend to be either very specialized and mathematically involved or popular, stressing the philosophical implications. In the 50-odd years of the new physics, which may be taken to have started with the first exposition of special relativity, our approach to the whole subject has changed radically. What started as a rather abstract discussion concerning the foundation of physics has become, in effect, the beginning of a second industrial revolution. To see this, one need only be reminded of what is probably one of the most important consequences of the theory—namely, the equivalence of mass and energy, so clearly demonstrated in the working of nuclear reactors and the "atomic" bomb.

The book for review reflects this modern approach and is aimed at the experimental physicist and student studying for an honours degree course in physics or mathematics. It can, however, also be recommended as a refresher to any physicist or engineer working in the nuclear field. The book develops the special theory of relativity in a clear, detailed and concise way. The only mathematical understanding required is a working knowledge of three-dimensional vector analysis. The complications of the tensor calculus often associated with an account of this subject have been entirely avoided.

In the first half of the book the theory is established and all aspects of the Lorentz transformation are considered in detail. In the remainder a large number of specific examples of applications of special relativity to both classical and modern physics are treated. These are rather sketchy and one wonders what benefit could be derived from this type of discussion. Surely, a student not already familiar with quantum mechanics will not make much of barely 10 pages starting with the uncertainty principle and concluding with a short note on relativistic Dirac wave mechanics. It is felt that this part of the book might usefully be expanded in a later edition. Finally, a bibliography gives useful material for further reading on the subject of each chapter.

W.S.

Books Received

Basic Electricity. Parts 1-5. (Based on a Course of Technician Training compiled by Van Valkenburgh, Nooger and Neville, Inc.) First British Edition (1959). Technical Press Ltd.; 1 Justice Walk, London, S.W.3. 12s. 6d. per Part and 55s. per Set.

Chemical Processing of Nuclear Fuels. By F. S. Martin and G. L. Miles. Butterworths Scientific Publications Ltd.; 88 Kingsway, London, W.C.2. (1958.) 40s.

Chemistry of Nuclear Power. By J. K. Dawson and G. Long. George Newnes Ltd.; Tower House, Southampton Street, Strand, London, W.C.2. (1959.) 30s.

The Neutrino. By J. S. Allen. Princeton University Press, Princeton, N.J., U.S.A., and Oxford University Press Ltd.; Amen House, Warwick Square, London, E.C.4. (1958.) 36s.

Nuclear Engineering Handbook. Edited by H. Etherington. McGraw-Hill Book Co., Inc., New York, N.Y., U.S.A., and McGraw-Hill Publishing Co. Ltd.; 95 Farringdon Street, London, E.C.4. (1958.) 194s.

A Dictionary of Metallurgy. By A. D. Merriman. MacDonald and Evans Ltd.; 8 John Street, Bedford Row, London, W.C.1. (1958.) 126s.

Atomic Terminology (Atomterminologie), the dictionary by L. Lettenmeyer reviewed in our April issue, is distributed in the British Empire by Temple Press Limited at 42s. 0d. per copy.

Technical Papers and Publications

Canadian Atomic Energy Development in Review and Prospect. By W. B. Lewis. (James Clayton Lecture delivered at a joint session of the Institution of Mechanical Engineers and the British Nuclear Energy Conference in April, 1959.)

In 1951, the heavy-water NRX reactor had been in operation for four years and experience had shown that 110 million B.t.u./lb U could be extracted from the metal elements without any re-processing, the metal retaining about 70% of its reactivity. This amounts to more than 3,000 MWd/t and a fuel cost substantially lower than that incurred in conventional plant. Recent experiments have indicated that 10,000 MWd/t can be obtained from oxide elements, resulting in a still greater difference of fuel cost. The NRU reactor, its design based on the experience available in 1951, is run continuously at high output, and operates at 288°C and 1,500 lb/in^2. The fuel elements consist of zirconium-sheathed uranium and facilities are incorporated enabling the elements to be changed rod by rod while the reactor operates at full power. All these items were new departures at the time.

There are altogether eight Canadian heavy-water reactors, either already working or in various stages of development. All plants mentioned are, or will be, operated with natural uranium, except NRX and ZEEP where fuel enriched with uranium-235 or plutonium has been used. Considerable experience has been gained with the latter and to date 5.5 kg of plutonium, re-irradiated in NRX in the form of plutonium-aluminium alloy rods, has yielded 1,500 MWd.

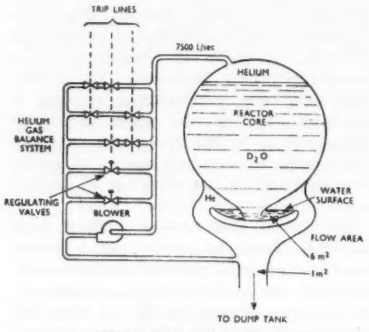
The author then turned to an account of his experience with deliberately initiated or accidental fuel failures due to rupture, while running on UO_2 clad in zirconium alloy. A rupture will be signalled by the presence of radioactivity in the water but, as the coolant circulates rapidly, identification of the element in question is difficult. A better means of detection could possibly be derived from the observation that a sudden change in operating power level usually releases a burst of fission products. The new facility of continuous on-power fuelling lessens somewhat the quality standards required for element cladding but relaxation should not be carried too far.

Heavy-water power reactors can be envisaged to be controlled entirely by the level of the moderator. From the outset, the NRX reactor contained provisions for adjustment of the moderator level. After the accident in December, 1952, the fine control rods were eliminated and shutting-down is now effected by means of a small number of shut-down rods only, plus dumping of the moderator. The basic idea is more fully developed in the design of the NPD-2 and CANDU where the moderator is kept "suspended" by balance of gas pressure. Shut-down rods are no longer used. In the case of a rupture the moderator will upset the gas balance in such a way that the moderator is rapidly dumped out. The diagram reproduced below shows the complete arrangement including the three parallel (independently working) trip circuits. By operating the controls appropriately, dumping can be effected at a rate exceeding any inflow from the coolant.

Table I. Canadian Heavy-water Reactors

ZEEP	Zero energy reactor for fuel and lattice research	First operated September 1945
NRX	40-thermal-megawatt experimental reactor	First operated July 1947
NRU	200-thermal-megawatt experimental reactor	First operated November 1957
CIR	Canada-Indian reactor. 40-thermal-megawatt experimental reactor	Under construction
NPD—2	Nuclear power demonstration 20-electrical-megawatt generating plant	Under construction. To operate in 1961
ZED—2	Zero energy reactor for lattice experiments. Larger than ZEEP	Under construction
CANDU	Full-scale power reactor, 200 electrical megawatt	Preliminary design study 1956-57. Under development.
OCDR	Organic liquid-cooled deuterium reactor, 150 electrical megawatt	Conceptual design 1958 by Canadian General Electric Co. Ltd.

Uneasiness has been expressed over the possibility of neutron flux instability associated with poisoning by the transient fission product xenon-135. It would appear that a reactor size is required which is smaller than the instability limit of radius (which is about 15 times the migration length) but may be near enough for sluggish, damped oscillations of the neutron flux pattern to arise. This indicates that control by a poison distributed throughout the moderator would be advantageous, if it were practicable. The NRU reactor is operated with a peak neutron flux in the fuel of about 3×10^{14} n/cm^2, sec. At this level the xenon poison transient following shut-down is large, but for a power reactor the figure need not be higher than, say, 1×10^{14} n/cm^2, sec and as a result, the xenon poison transient would be significantly smaller. In the NPD-2 reactor a booster fuel rod of enriched uranium-235 will be used to obtain 30 min override of the xenon poison transient by an extra 3.5 mk of reactivity. The rod is withdrawn when power is re-established and therefore could last a long time. This design should be much cheaper than any existing method of adding this amount of reactivity but in the case of large reactors provision of the device may not be worth while.



NPD–2 Reactor Shut-down System
Simplified schematic.

Nuclear Metals. By A. B. McIntosh. (Paper presented at a joint meeting of the North Wales Metallurgical Society and the North Wales Section of the Royal Institute of Chemistry in March, 1959.)

The speaker began by giving a general outline of solid state problems relevant to the nuclear power programme in this country. These include studies of the graphite moderator, the uranium fuel, the magnesium alloy can and the steel pressure vessel which contains the reactor core. The function of the very large quantities of graphite in a thermal reactor of the Calder type is to slow down the fast neutrons to thermal energies by succeeding collisions. This process inevitably causes damage to the graphite crystal lattice which manifests itself in the form of atoms displaced to interstitial positions between the crystallite layers. The atoms possess potential energy by virtue of their position, and the total stored energy in the lattice depends on the number of displaced atoms, which again is a function of the neutron dose at any particular temperature. The author outlined the implications of this storage of energy from the standpoint of reactor operation, and mentioned existing methods whereby it may be released periodically. Turning to various aspects of the dimensional stability of uranium during irradiation or thermal cycling, the problem of growth was dealt with first, followed by the problem of swelling. The latter becomes important at temperatures above 400°C. The reasoning was given which leads to the conclusion that swelling is due to the coalescence of rare gas fission product atoms into bubbles which exert a pressure on the matrix causing it to expand. The speaker then gave a short summary on creep data for uranium and its alloys, emphasizing in particular, the importance of internal stresses generated in anisotropic materials by thermal cycling, on the creep rate. On the subject of magnesium canning materials the current theory on the relationship between the elongation to rupture of the materials at various strain rates and the incidence of cavities along grain boundaries was outlined, showing that a maximum in the

level of cavitation was related to a minimum in the ductility. Finally, Dr. McIntosh examined briefly some of the problems involved in the fabrication of mild-steel pressure vessels up to 70 ft in diameter, referring in particular to the risk of brittle fracture and the effect of irradiation on the brittle-ductile transition temperature.

Boron in Steel. By F. B. Pickering. (Paper presented to the Liverpool Metallurgical Society in April, 1959.)

The lecture briefly considers the steelmaking of boron steels, and then discusses the solubility and diffusion of boron in iron and steel, together with adsorption effects of boron at austenite grain boundaries. This is related to metallographic tests for boron in steels and to the effect of boron on hardenability. The effect of boron is considered on the isothermal transformation of austenite and on the martensite reaction and theories for the mechanism of the effect of boron on the hardenability of steel are discussed. Finally, the effect of boron on the mechanical properties of steel is considered, and also its effect upon the tempering characteristics of steels.

Methods of Improving Heat Transfer from Condensing Steam and Their Application to Condensers and Evaporators. By D. C. P. Birt, J. J. Brunt, J. T. Shelton and R. G. H. Watson. (Paper presented at the spring meeting of the Institution of Chemical Engineers.)

The results of work at the Admiralty Materials Laboratory on certain aspects of the use of rotating surfaces and dropwise condensation promoters to increase the heat transfer rate from condensing steam are related. Cylindrical rotating condenser surfaces behave in a similar way to that reported for rotating conical surfaces, and a substantial improvement in steam-side heat transfer coefficient may be achieved. It has been shown that injection of dropwise promoters into steam is a valuable technique for maintaining high heat fluxes, even with short-lived promoters. The variation of the steam-side heat transfer coefficient with heat flux has been studied in a single tube flash evaporator and in a single tube model condenser. It is concluded that there is no variation of coefficient with heat flux in the range of 12,000 to 150,000 B.t.u./h, ft^2. Field trials in a 25 ton/day evaporator and a model condenser have shown that improvements in overall heat transfer coefficients of about 30% can be achieved by using dropwise promoters.

Problems in the Production of High Vacua in Large Equipment. By J. Blears. (Paper presented at the Symposium on Current Developments in the Production of High Vacua, organized by the Institute of Physics in April, 1959.)

It is becoming accepted that the factors of most importance in the design of high vacuum systems for nuclear physics are surfaces and the materials from which they are made. Surfaces may adsorb, desorb, distil or decompose and to deal with the gases and vapours coming from them we need pumps and traps which reduce rather than increase the complexity of surface phenomena. We also need to know what pressure is needed and what condition must be obtained at the surfaces if the vacuum system is to function correctly. Exact guidance on the latter points, especially guidance based on evidence, is usually difficult to obtain and decisions are still frequently made in terms of convenience and available capital. Some time must elapse before specification and design of vacuum systems becomes an exact science, but progress is being made in compilation of data on the degassing of surfaces under various operating conditions. Scale models have been used as an aid for predicting pressures in large bakeable systems and observations on a number of different large systems have given confidence in a method for predicting pressure-time curves for complete systems from results of laboratory experiments on their materials of construction. It is known that reactions between electrons, ions and surface adsorbents can give rise to the formation of deposits which adversely affect the operation of equipment utilizing electron or ion beams or high voltage gradients. The desire to avoid such deposits has led to the use of mercury diffusion pumps and more recently to the application of ion and getter pumps. A corresponding development has taken place in the use of oil diffusion pumps with refrigerated baffles. Numerical treatment of surface and gas phase problems and comparison between predicted and actual performance may, in time, lead to it becoming possible to remove some of the uncertainty which is still present in vacuum engineering. Results and comparisons of recent installations are given.

The Vacuum System of the 7 GeV Accelerator. By S. H. Cross. (Paper presented at the Symposium on Current Developments in the Production of High Vacua in April, 1959.)

The 7 GeV Proton Synchrotron being built at Harwell for the NIRNS (described in *Nuclear Engineering*, April, 1959) will be the largest accelerator in this country when it is completed at the end of 1961 and one of the biggest accelerators in the world. The design of the vacuum system raises problems peculiar to this type of machine. The vacuum vessel must work in an intense and varying magnetic field and must, therefore, be of non-conducting material; for economical machine design, the vertical aperture of the vessel must be as large as possible, to make the best use of the magnetic gap and so the horizontal walls must be thin; when the machine is operating, the vessel will be subjected to intense radiation and its mechanical and vacuum properties should remain unaffected; because of the long distance travelled by the protons the pressure must be very low to keep down the loss due to scattering by the residual gas molecules. The structural materials which most nearly meet these requirements are the glass-fibre reinforced epoxy resins and details of work on the vacuum and radiation stability of these materials are given. Pumping parameters for equilibrium conditions can be derived and the total required pumping speed deduced. The pumping system must have a low back-streaming rate, as oil molecules would make the scattering effects worse. Its controls must provide the maximum protection primarily to the vacuum vessel and secondarily to the pumping unit itself, and, since access to the machine is prohibited during operation owing to high radiation levels, the whole system must be capable of being controlled remotely.

The design of pumping units and vessel which has now been evolved seems the best compromise between the different requirements and is described in some detail.

Characteristics of Some Pumps and Experimental Results. By B. D. Power. (Short paper contributed to the discussion of the lecture by S. H. Cross, see abstract above.)

The characteristics of the oil vapour pumping groups to be applied to the system discussed by Mr. Cross are described in relation to the selection factors dealt with by Mr. Blears and contrasted with the characteristics of similar mercury vapour pumping groups. The interpretation of small-scale experimental data to predict large-scale systems is commented on.

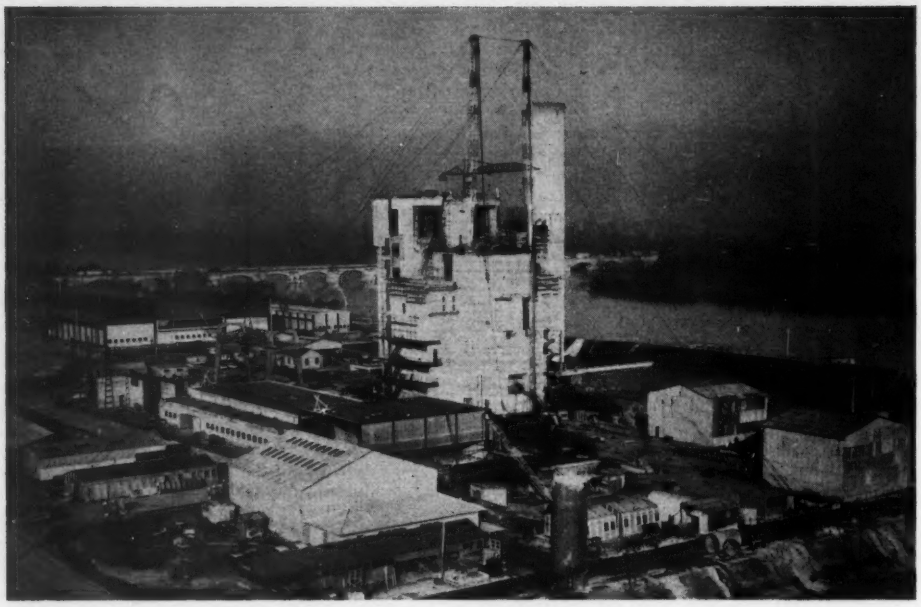
Some Results of Vacuum Studies Relating to Large Machines. By R. S. Barton. (Short paper contributed to the discussion of the lecture by S. H. Cross, see abstract above.)

The need for lower pressures in large accelerators and thermonuclear machines has called for more complete knowledge of the outgassing rate, vapour pressure and gas permeability of various materials involved in construction. For this reason apparatus was set up, in the laboratory of the Vacuum Group of the Controlled Thermonuclear Research Division at Harwell, to study such phenomena. Some of the results are discussed.

In the report of Sir Leonard Owen's paper on p. 179 of the April issue, incorrect values have been given for the leak rates mentioned in connection with the mass spectrometer method, and for the maximum permissible content of beryllium in the atmosphere. The correct values are—

A leak rate of the order of 0.01 clusec can be detected. It has been shown experimentally that a leak rate of 1 clusec of helium under these conditions, corresponds to a cylindrical hole 0.001 in. diameter and 0.03 in. long.

The maximum content of beryllium metal dust or fine particles of oxide in the atmosphere must not exceed 2/1,000,000 g/m^3.



The first French civil nuclear station at Chinon, on the river Loire, nears completion. Built by Electricité de France, the 60 MW plant is expected to go critical this year.

World News

International

DRAFT AGREEMENTS have been approved by the IAEA between the Agency and the U.S.S.R., the U.K. and the U.S.A., for the supply by these countries of nuclear materials to the Agency. The U.S.S.R. has agreed to supply 50 kg of uranium-235 in any concentration up to 20%, in metallic form or in chemical compounds or as fabricated fuel elements. The U.K. will supply 20 kg of uranium-235 in any concentration up to 20% enrichment in the 235 isotope and the U.S.A. will supply 5,000 kg of contained uranium-235 plus additional amounts of nuclear materials to match bequests from other countries to the Agency.

PLANS for establishing a functional laboratory on a site adjoining the Austrian reactor and nuclear laboratories at Seisbersdorf, near Vienna, have been approved by the IAEA. The laboratory will work on the standardization of isotopes and preparation of radioactive standards.

THE BOARD OF GOVERNORS of the IAEA are considering the summary reports on the preliminary missions sent by the Agency to the United Arab Republic, Greece, Burma, Ceylon, Indonesia and Thailand. Proposals include the extraction of uranium from Egyptian phosphate ores and the production of heavy water at Aswan.

TWO INTERNATIONAL courses on nuclear energy, designed for the teaching staffs of universities and higher technical colleges, will be run by the European Nuclear Energy Agency of the O.E.E.C. at Harwell and Saclay. They will be held from July 20 to 31 and will be limited to about 50 applicants.

The vice-president of the Japan Atomic Power Company, Dr. T. Ipponmatsu, recently concluded an agreement with the AEA for assistance in the Japanese nuclear power programme. On the right is Lord Plowden, who handed Dr. Ipponmatsu a letter of intent, concerning the supply of fuel for the 150 MW power station to be built by G.E.C./Simon-Carves.

FIFTEEN COUNTRIES have agreed to make voluntary contributions to the IAEA and monetary assistance already received totals $872,947. The sum required is $1,500,000.

United Kingdom

OLDBURY-ON-SEVERN has been chosen by the Central Electricity Generating Board as a prospective site for a nuclear power station. The site is on the south-eastern bank of the Severn estuary, 14 miles north of Bristol and could accommodate a station of 1,000-MW capacity. One of the main advantages of the site is a rock shelf offshore which will be used to create an artificial tidal reservoir from which large quantities of water required for cooling condensers of the steam turbines can be drawn during low tide. Foundation conditions on shore are reported to be good for supporting heavy reactors.

THE DUMFRIES-SHIRE County Council have been invited by the AEA to nominate two representatives to a liaison committee to deal with any emergencies at Chapelcross. The 140 MW power plant will be officially opened on May 2.

THE 37TH MILAN FAIR (April 12-27) contained a 3,500 sq ft exhibit by the AEA illustrating the industrial development of power reactors and the extensive range of radioactive isotopes which the AEA supply all over the world. The power reactor section makes special reference to the Latina station.

BLUEPRINTS and documents of the reactor for Dreadnought have arrived in Britain from the United States. Rolls-Royce and Associates is the company handling the installation.

Australia

SIR LEONARD OWEN, managing director of the industrial group of the U.K. AEA, and Sir Thomas Playford, Premier of South Australia, have recently had talks on the future of nuclear power for the State. Sir Leonard Owen has undertaken to obtain information on the requirements for a medium-size nuclear station to operate from 1962 and on the training facilities for technicians from South Australia in the United Kingdom.

Canada

A LOW POWER REACTOR to be known as ZED-2, designed for testing fuel rod arrangements in large power reactors, is to be built at Chalk River for Atomic Energy of Canada. Costing about three million dollars, the reactor is being built by Foster Wheeler. It will have a power output of 100 watts and will be moderated with heavy water. During the early experiments the fuel will be bundles of uranium oxide rods.

EXPORTS OF URANIUM ORES and concentrates were 72% higher in February than the previous year. The value for February was $25 million as compared with $14.5 million of last year.

France

TWO RW-300 digital computers, to detect and locate ruptured fuel cartridges, will be installed at the nuclear power station under construction at Chinon. One RW-300 computer will be connected to the system when the plant goes into operation in a few months' time and the other will be installed later in the year.

Italy

CNRN HAVE AWARDED the first contracts for the construction of the Nuclear Study Centre which will be built at Casaccia, near Rome. The centre will house a TRIGA Mark 2 reactor which is expected to go critical at the end of the summer.

THE MINISTRY FOR INDUSTRY has allotted more than 5,000 million lira in the 1959-60 budget to cover research, study and experiments in the nuclear field. This means that about 50% of the research budget has been allotted to nuclear energy: the sum is only half the amount asked for by the National Committee for Nuclear Research.

AFTER DISCUSSIONS with Euratom, the Nuclear Committee, recently established by the Italian Federation of Industries, has joined in the appeal to Parliament for a nuclear legislation concerning insurance against nuclear risks. Other bodies interested are the Italian Nuclear Energy Forum and the CNRN.

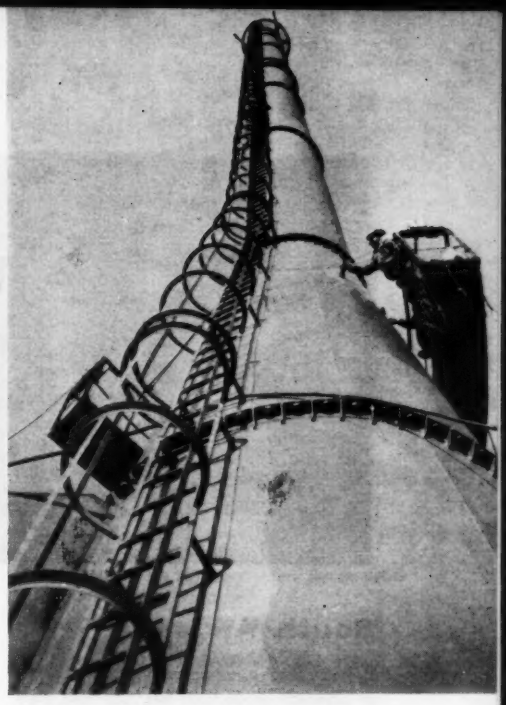
Japan

THE CONTRACT for a 12.5-MW nuclear power station has been awarded by the Japan Atomic Energy Research Institute to International General Electric of the U.S. The plant, an enriched uranium power reactor, will be located at Tokai-Mura, near Tokyo, where the 150-MW power station is to be built by General Electric Simon-Carves of the U.K. The reactor is of the direct cycle boiling water type with natural circulation cooling; it is expected to go critical late 1961.

Netherlands

A REACTOR for agricultural tests is to be erected at the Institution of Atomic Energy in Agriculture at Wageningen. Expected to be ready in 1961, the reactor will be used mainly in tests on mutation improvement and food preservation.

PROPULSION OF SHIPS by nuclear power figures in the conferences held at the Technical Trade Fair (April 15-24) in Utrecht. Ship owners and builders from Britain, U.S.A., Canada, Germany, Norway, Sweden, Iraq and Japan are attending.



A 250-ft high exhaust chimney at Italy's first nuclear research centre at Ispra, near Varese, which was opened on April 13 by President Gronchi.

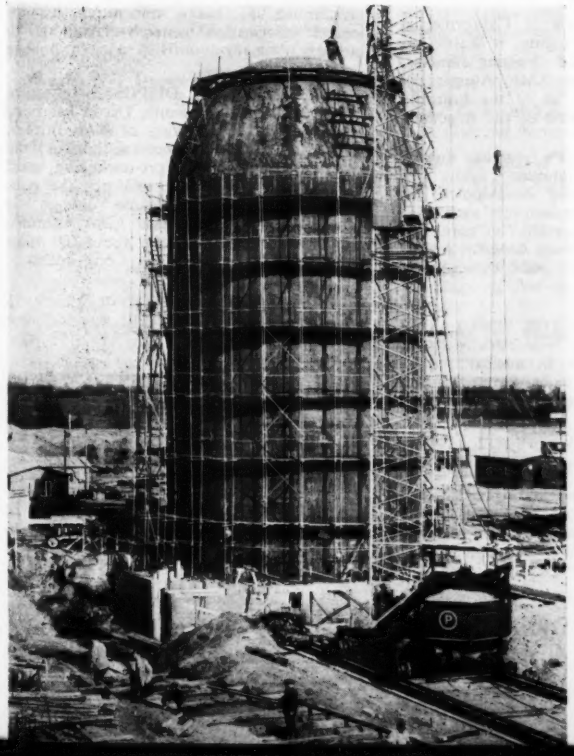
AN ESTABLISHMENT, the Foundation for Geological Exploration in Netherlands New Guinea, has been formed by the Government for the investigation of minerals for nuclear energy. A mining bill for the territory will be submitted providing freedom of operation for foreign nationals as required by the European Economic Community Treaty.

Nigeria

A SURVEY for radioactive materials is being undertaken in West Nigeria by the nuclear energy division of the Geological Survey of Great Britain.

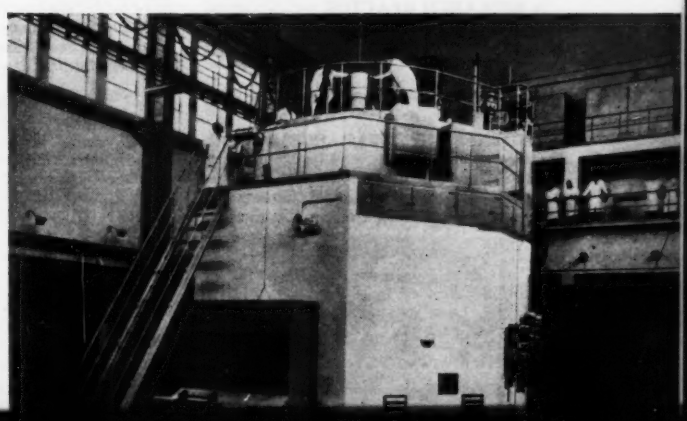
Republic of Vietnam

A CONTRACT has been awarded Kaiser Engineers and Constructors of Washington to provide plans for reactor buildings, laboratories and other facilities for the Institute of Nuclear Research at Dalat. A TRIGA Mark 2 reactor will be housed in the Institute.



The 150-ft high, 40-ft diameter containment vessel for the 15 MW BWR being built for R.W.E. at Kahl near Frankfurt. The reactor is scheduled for completion next year according to the contract between A.E.G. and I.G.E.

The first Hungarian experimental reactor which began operating on March 25 at Cailleberg. The 2-MW tank-type unit was built with the help of the U.S.S.R. Moderated with light water, the core is made up of 52 units, most of which contain 16 aluminium-clad uranium rods. Maximum flux is 2.10^{13} n/cm², sec.



The homogeneous power reactor, LAPRE 2, at the Los Alamos Scientific Laboratory. The reactor has been designed to produce superheated steam in one operation; it is expected to generate 1 MW of heat.

South Africa

IN ITS ANNUAL REPORT for 1958, Randfontein Mine, now primarily concerned in uranium production, has said that each pound of uranium produced last year cost 73s. 3d. before allowing for uranium loan repayments and interest. The price received from the Atomic Energy Board is 94s. 4d. under the existing 10-year contract.

Spain

JUNTA DE ENERGIA NUCLEAR and Westinghouse Electric of the U.S. are jointly studying a new concept for a nuclear power station to be built in Spain. The reactor will be of 20 MW capacity and will be similar to the modified type of water-cooled and moderated reactor Westinghouse are developing for the Carolinas-Virginia Nuclear Power Associates.

Sweden

A SECOND DELAY in the construction of the commercial reactor plant, R3/Adam, at Stockholm has been announced. Reasons given are that a larger rock chamber is necessary and that additional structures, including gas-tight steel-clad concrete walls, are also needed. The plant was originally expected to come into operation 1960-61 but is now only expected to be finished some time in 1963.

PRODUCTION of fuel elements has begun in an experimental laboratory near Stockholm. The fuel elements are made from sintered uranium oxide pellets. They are being made for the R3/Adam nuclear power plant at Farsta.

U.S.S.R.

A RESEARCH REACTOR with a thermal capacity of 1 MW is being built at the Byelo Russian Academy of Sciences.

U.S.A.

ANOTHER NUCLEAR SUBMARINE, the *George Washington*, will be launched at Groton, Connecticut, on June 9. The submarine will have a mobile underwater platform for launching Polaris missiles.

A DESIGN MODIFICATION for the sodium graphite reactor power plant being built for the Consumer Public Power District, Hallam, Nebraska, is expected to allow for the eventual construction of a food irradiation facility. Liquid sodium which transfers heat from the reactor to the steam generator, and is made radioactive by the process, would be used as the source material for preserving and sterilizing food.

A CONFERENCE, the third, will be held on analytical chemistry in nuclear reactor technology at Gatlinburg, Tennessee, on October 26, 27 and 28.

MOST OF THE MAJOR EQUIPMENT for the reactor containment building has been installed on the Enrico Fermi Atomic Power Plant at Monroe, Michigan. The control building and steam generating building are expected to be completed early this month.

THE AMERICAN SOCIETY of Mechanical Engineers have produced a book containing detailed information on 95 reactors in the U.S., Canada, South America, Western Europe and Asia, called *Nuclear Reactor Plant Data-Research and Test Reactors.*

THE UNIVERSITIES of California, at Los Angeles, and Washington, at Seattle, are to have research and training reactors designed and built by AMF Atomics of New York. They will be of the Educator type, an improved version of the Argonaut.

REMOTE LOCATION reactor, dubbed SM-2, with a minimum rating of 6,000 MW(E) is under development by Alco Products. Present contract with AEC calls for final development of core and overall design work is being done for Army's Engineering Research and Development Laboratories.

A NUCLEAR REACTOR SIMULATOR is to be installed at the New York Maritime College, where courses in nuclear physics have been run for eight years. Leeds and Northrup will supply the unit.

A HOMOGENEOUS power reactor experiment, designed to produce superheated steam in one operation, is being tested at the AEC laboratory in Los Alamos by the University of California. The reactor, LAPRE 2, achieved criticality on February 26.

PROPOSALS FROM INDUSTRY for performance under a cost-type contract of engineering development work, for concepts and materials most suitable for advanced design reactors capable of using superheated steam, have been called for by the AEC.

AN UNCLASSIFIED, technical information meeting will be held by the AEC at Idaho Falls during May, on the construction, operation and use of test reactors. The meeting will be devoted to the technical design and conduct of experiments, safety considerations and experience gained from operating test reactors.

THE PUBLIC ARE to have the opportunity of questioning the safety aspects of all reactor projects in the AEC's power demonstration reactor programme. Previously the public have only been able to participate in safety considerations of privately owned reactors built under AEC licence. The new arrangement will give them the same opportunity with reactors owned by the Commission.

A $6,500,000 metals and ceramics building is to be constructed at Oak Ridge National Laboratory. The contract has been awarded to Giffels and Rosetti of Detroit and construction is expected to begin late this year, finishing by the end of 1961.

THE GENERAL CONTRACTOR for the construction of the nuclear portion of the Hallam Nuclear Power Facility at Hallam, Nebraska, will be Peter Kiewet Sons of Omaha. The $9,000,000 contract is for a sodium-cooled, graphite-moderated reactor, designed to produce 75 MW.

DOMESTIC URANIUM ORE RESERVES in the U.S. have been estimated at 82¼ million tons. Uranium is being processed at 23 uranium mills, including one Government-owned at Monticello, Utah. The combined rated daily capacity is 21,065 tons of ore per day. Total estimated capital invested is $134,928,000.

THE TOTAL of patents released for public use by the AEC is now 1,171. The Commission grant non-exclusive, royalty-free licences on listed patents as part of its programme to make non-secret technological information generally available to industry.

A LICENCE FOR DISPOSAL of radioactive waste in the Atlantic Ocean has been given to Walker Trucking of New Britain, Connecticut. The licence authorizes the company to collect pre-packaging and labelled waste materials, reinforce the containers with concrete dense enough to ensure sinking to at least 1,000 fathoms, and deposit them at a point about 100 miles due east of Montauk Point, Long Island.

ONE POWER REACTOR and 21 research reactors were licensed during February and March by the AEC.

THE FISSION PRODUCTS pilot plant at Oak Ridge National Laboratory has begun routine separation and concentration of large quantities of radioisotopes from reactor fuel wastes. The plant began experimental operations last August and is equipped for separating, purifying and fabricating kilocurie quantities of radioactive elements which previously were available only in limited amounts.

Personal

Appointments

Lieutenant Commander B. F. P. Samborne as first officer to command the submarine *Dreadnought*. Engineer Officer will be **Lieutenant Commander P. G. Hammersley.**

Mr. D. H. Hill as the nuclear energy attaché to the British Delegation to Euratom in Brussels.

Mr. D. A. Senior as Scientific Attachè to the British Embassy in Moscow.

Mr. W. H. McFadzean as the President of the Federation of British Industries.

Mr. W. E. Chamberlain as divisional vice-president of American Machine and Foundry, Atomic Energy Group.

Mr. C. G. P. Yarnold as technical liaison officer for the Owen Organization Group, Atomic Energy Committee.

Mr. J. A. R. Kay as managing director of A. V. Roe.

Sir Charles Westlake as director and chairman and **Mr. J. Black** and **Mr. H. O. Houchen** to the board of Avo.

Mr. F. S. Clark and **Mr. P. G. Rennie** as directors of Laporte Titanium.

Mr. W. E. Ogden and **Mr. P. Wrightson** to the boards of the Iron Trades Employers' Insurance Association and the Iron Trades Mutual Insurance Company.

Mr. L. Bailey a director of United Steel Structural.

Mr. J. D. Turner vice-chairman of Production Tool Alloy.

Sir Paul Benthall a director and elect chairman of the Amalgamated Metal Corporation.

Mr. J. S. Brough as technical director and general manager of Humphreys and Glasgow.

Mr. R. W. Deuster as European sales representative for Babcock and Wilcox, U.S.A.

Mr. W. H. Heydon to the board of William Press and Son.

Mr. L. Rumley as manager of Industrial Hydraulics Sales.

Mr. L. Rumley.

Mr. W. H. Heydon.

Mr. C. G. P. Yarnold.

Mr. W. H. McFadzean.

Mr. G. B. R. Feilden.

Mr. S. M. Orr.

Mr. H. G. Herrington as chairman of the Aluminium Industry Council for a third term of office.

Mr. G. B. R. Feilden to the Fellowship of the Royal Society.

Mr. A. H. Hird to the board of English Electric.

Mr. G. W. Dunkley as a director of Westinghouse Brake and Signal.

Mr. C. W. Simpson as company secretary and accountant of Keeton, Sons.

Mr. I. W. Trench as sales manager for the Scottish area of Klockner Moeller (England).

Mr. W. I. Pumphrey to the Court of Governors of the University of Birmingham.

Mr. D. Selby as Press officer to the Wimpey Organization.

British Compressed Air Society announce the following: president, **Mr. E. A. Martin;** vice-president, **Mr. J. C. Greig;** technical director, **Mr. T. C. Hore;** publicity officer, **Mr. H. S. Parsons.**

Mr. K. F. Petersen as marketing manager of the Industrial Electronics Division of Allen B. du Mont Laboratories.

Mr. J. H. Sutcliffe-Ross as sales manager of Metropolitan Electric Cable and Construction.

Mr. D. M. Cherry as transmission plant and equipment design engineer at headquarters and **Mr. M. H. Shepheard** as an architect in the chief design and construction engineers department of the C.E.G.B.

Mr. G. Laing to the board of Miller Insulation and Engineering.

Mr. C. A. McLaren as works manager of Dewhurst and Partners.

Mr. H. Baker managing director of Marconi (South Africa).

Plessey Nucleonics announce the following: **Mr. G. V. Hough** as advanced projects manager, **Mr. J. S. Crick** as sales manager, **Mr. R. G. Jolliffe** and **Mr. A. Trott** to join the office of **Mr. B. Daniel,** sales liaison engineer.

Mr. D. C. Gunn as chief engineer of Cochran.

Mr. P. H. Leyton as director of engineering of Black and Decker.

Mr. I. E. Williams as secretary and **Mr. R. L. Fenwick** as field manager for the U.K. of Quickfit and Quartz.

Mr. C. H. Glassey as chairman of the British Industrial Plastics. **Mr. J. E. Beard** and **Dr. W. Blakey** have been appointed joint managing directors.

Mr. S. M. Orr as works manager of Steels Engineering Installations.

Mr. L. Rotherham has been co-opted to the Council of the British Welding Research Association.

Sir George Dowty and **Mr. R. F. Hunt** to the board of Rotol.

Mr. B. R. Scholes chairman of the North-East Regional Council of the British Institute of Management.

Major J. F. E. Clarke chairman of the Audio Manufacturers' Group of the British Radio Equipment Manufacturers' Association.

Resignation

Mr. E. Diamond has resigned as Associate General Counsel of the AEC.

Retirements

Sir Edward Crowe from the board of English Electric.

Sir Ewart Smith from the position of deputy chairman of I.C.I.

Mr. W. Gardner as chairman of the Amalgamated Metal Corporation.

Mr. D. M. Cameron and **Captain Q. H. Paterson** as directors of William Beardmore.

Tours

Mr. J. K. Vaughan-Morgan, Minister of State at the Board of Trade, to the International Samples Fair in Milan.

Mr. V. Hessen and **Mr. D. Jackson** to the United States and Canada to demonstrate Pye television cameras for gas-cooled and heavy water moderated reactors.

Mr. W. A. Hartop of George Kent to South Africa and the Central African Federation.

Mr. S. Cole, director-general of the IAEA, to Bulgaria, Greece, Hungary, Israel, Rumania and Turkey.

Obituary

Nuclear Engineering regret to announce the deaths of the following:—

Sir Ashley S. Ward, president of Thos. W. Ward, at the age of 81.

Mr. J. L. P. Brodie, engineering director of de Havilland Engine, at the age of 59.

Industrial Notes

Jessop-Saville have recently installed a Heraeus consumable arc melting furnace capable of melting titanium ingots up to 24 in. diameter and weighing more than 2½ tons, and a Wild Barfield/N.R.C. high-frequency induction melting furnace.

Westinghouse Electric International have developed a television camera tube capable of memorizing what it sees. The new tube, called Permachon, operates as an electronic film which instantly records a scene on a television picture tube.

Wild-Barfield Electric Furnaces are exhibiting at the British Trade Fair, Lisbon, the Poznan International Fair and the 5th Salon de la Chimie, Paris.

The Imperial College of Science and Technology are holding a course on nuclear chemical technology in October.

Elliott-Automation have formed a new subsidiary company, **The Swartout Company,** to manufacture all electronic control systems for the process industries, heating and ventilating and power station instrumentation.

Lockheed have devised a method at the Georgia Nuclear Laboratories of predicting low-level blankets of air that may make the running of nuclear reactors inadvisable.

British representation in the St. Erik's Fair, Stockholm (September 2-13) will be organized by **Trade Fairs and Promotions,** Drury House, Russell Street, London, W.C.2.

The Council of the **British Institution of Radio Engineers** is to establish four additional premiums for the authors of outstanding papers published in the Institute's journal.

English Electric are to install a Deuce electronic digital computer at the University of Liverpool, Ashton Hall Mathematical Laboratories.

Metal Industries have made an offer for the 2,500,000 shares in **Avo** and acceptances in respect of more than 90% of the capital have been received.

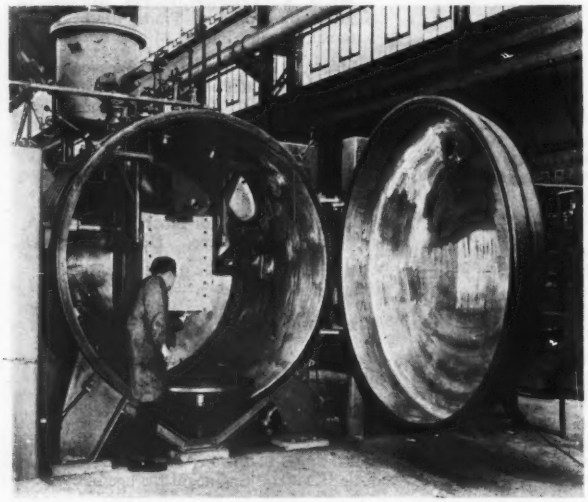
Vitro of New York are to provide architect-engineer services for a portion of the new $3,500,000 pilot plant at Oak Ridge National Laboratories for the development of chemical reprocessing methods for radioactive fuels.

By installing a new 28½-in. container, **Moffat Engineering** have been able to increase the extruded lengths of large diameter, heavy wall pipes by as much as 125%. Largest changes are in the 16-in. to 20-in. o.d. size for main steam power plant applications, making considerable savings through elimination of welds in 2-in. to 4-in. wall pipe.

An agreement has been reached for **North American** to acquire **Foster Wheeler** by the issuance of one share of North American stock for each share of Foster Wheeler. Atomics International are also a subsidiary of North American.

Ruston and Hornsby and **Gray Tool,** of Houston, Texas, have recently signed a licence agreement for Rustons to exploit patents which are already established in the U.S.A. The patents cover high pressure and temperature connections utilizing a new sealing system for efficient and high-speed connection of standard pipe sizes.

The 11th **British Electrical Power Convention** will be held in Torquay from June 1 to 6.



The 600 lb Wild Barfield/N.R.C. high frequency vacuum induction melting furnace at the Jessop-Saville works in Sheffield.

A cut-away of the Ruston-Grayloc connection showing the sealing system.

The 1959 German Industries Fair at **Hannover** is being held from April 26 to May 5. **Vickers,** in co-operation with the AEA, are showing a model of a light water moderated training, research and isotope reactor.

British Insulated Callender's Cables have a new telephone number for their Bournemouth depot, Bournemouth 36223. The Cambridge address of the company is now 65 Devonshire Road. Telephone, Cambridge 55451/2.

A new method of packing wide reels of aluminium converter foil has been developed by **Star Aluminium.**

Northern Aluminium are to establish a new branch in New Zealand with an initial production capacity of 5,000 tons per annum of aluminium sheet and foil products and 2,000 tons per annum of aluminium wire and cable.

The **Business Efficiency Exhibition** will be held at Olympia from May 25 to June 4.

A new office for the major part of administrative staff of **Delapena and Sons** has been opened at Tewkesbury Road, Cheltenham, Glos. Telephone, Cheltenham 56341.

Crompton Parkinson have announced substantial price reductions for their tacho-generators.

Elliott-Automation have moved their London office to 34 Portland Place, W.1. Telephone, Langham 9271.

The International Congress and Exhibition for Instrumentation and Automation will be held at Düsseldorf from October 19-26.

English Electric have opened a new sub-office at 14 Albert Road, Middlesbrough. Telephone, Middlesbrough 44346/7.

Short and Mason are to open a branch office at 30A London Road, Manchester, 1. Telephone, Central 3044.

Weldcraft, who recently became part of the G. D. Peters group, have moved to Windsor Works, Slough, Bucks. Telephone, Slough 23201.

Isotope Developments report considerable interest in their 1700 scaler at the Leipzig Fair.

Johnson, Matthey have acquired an interest in **Metalli Preziosi** of Milan, a precious metal refining and manufacturing company.

A new oil-fire tunnel kiln has been installed at **Thos. Marshall,** for burning hollow fireclay refractories.

Londex have appointed **Harold Hubbard, Ltd.,** of 2 Aylsham Road, Norwich, as their technical sales representative for Norfolk and Suffolk.

An international compressed air and hydraulics exhibition will be held in conjunction with the second **European Fluid Power Conference** at Olympia on April 25-29 next year.

The British Exhibition in New York will open on June 10, Coliseum Buildings. Sir Norman Kipping, director general of the Federation of British Industries, and Mr. W. P. N. Edwards, a director of the Federation, are at present in the U.S. making preliminary arrangements.

The Electric Motor Division of **Newman Industries** has opened an additional office at 59 Grey Street, Newcastle-on-Tyne. Tel: Newcastle 2-3970.

The South East London Technical College six months full-time course for the **Institution of Electrical Engineers—Part 3** and/or **Institution of Mechanical Engineers—Part C, Examinations,** will run from October, 1959 to May, 1960.

Radiation Dynamics, of New York, have developed a high-powered particle accelerator producing an extremely large beam output at constant potential. Two models are available, 1.5 MeV, 15 kW and 3 MeV, 30 kW.

A Russian delegation viewing equipment at the EKCO Electronics works, Southend-on-Sea.

Morgan Crucible are showing two furnaces, the Birlec Morgan electric diecasting furnace Mark 2, and the oil fired Morgan basin tilter, at the Foundry Exhibition (Bingley Hall, Birmingham, May 21-30).

Hivac have introduced two new subminiature tubes, the H.F. double triode XR9 and the twin trigger cathode tube XC 24, to their range.

Communications Systems have changed their Sheffield address to 27 Collegiate Crescent.

Davis and Thompson will now be known as **Datum Metal Products.**

A conference on **Quality in Industry,** organized by the **Institution of Production Engineers,** the Institution of Engineering Inspection and the British Productivity Council, will be held at the Palace Hotel, Buxton, June 18-19. Inquiries should be directed to The Conference Secretary, The Institution of Production Engineers, 10 Chesterfield Street, Mayfair, London, W.1.

Babcock and Wilcox will illustrate their participation in the construction of nuclear power stations as part of their exhibit in the Scottish Industries Exhibition (September 3-19).

The **International Transistor Exhibition** will be held at Earl's Court from May 21-27. Manufacturers in this field will be exhibiting the latest development in transistor technology as well as computers and ancillary equipment.

An agreement between **Savage and Parsons** and **Marconi's Wireless Telegraph** will mean an extension of activities on the part of Savage and Parsons to cover closed circuit industrial television equipment to nuclear research and experimental establishments. The television equipment will include the Marconi Vidicon camera and 14 in. picture monitor.

National Engineering Laboratory will be the new name of the Council for Scientific and Industrial Research, Mechanical Engineering Research Laboratory at East Kilbride.

Ruston and Hornsby announce that their NFB gas bearing circulator has been selected by John Brown and Co., Ltd., for installation on the refuelling machine of the Advanced Gas-cooled Reactor at Windscale. The circulator will be mounted on the charge-discharge machine and will provide gas circulation for cooling the irradiated fuel elements during the withdrawal process.

Catalogues

The March issue of the **Wild Barfield** heat-treatment journal contains an article on modern heat-treatment equipment. (Watford, Herts.)

Platinum Metals Review, issued by **Johnson, Matthey** includes an article on the electrochemical properties of platinum in the April edition. (Hatton Garden, London, E.C.1.)

A new publication, *Atomic Energy Law Journal*, is announced by **Warren Publications** of Boston, Mass. It will be a quarterly journal for attorneys and executives engaged in the nuclear energy field.

The Metrovick 950 digital computer is fully illustrated in a new catalogue by **Metropolitan-Vickers.** (Trafford Park, Manchester.)

An ionization chamber laundry monitor is described in a recent publication by the **Brookhaven National Laboratory,** BNL 531 (T-133). (Upton, New York.)

Metals for nuclear energy and Zirconium weight tables are two recent publications by **I.C.I. Metals** division. (Millbank, London, S.W.1.)

The Fairey Review for March has a description of the forming and composition of **Atomic Power Construction.** (24 Bruton St., London, W.1.)

General Catalog R is the title of a publication by **Nuclear-Chicago** which shows an extremely comprehensive range of instruments and illustrates the research of the company in the nuclear field. (223 West Erie St., Chicago 10, Illinois.)

G.E.C. published, in their March issue of the *Atomic Energy Review*, articles on the Japanese acceptance of their tender for a power station and the technical co-operation set-up between them and Fuji Electric. (Kingsway, London, W.C.2.)

Ericsson have published a revised catalogue layout for electronic and nucleonic instruments. (22 Lincoln's Inn Fields, London, W.C.2.)

Wiggin Nickel Alloys have produced a booklet illustrating the corrosion resistance and other physical properties of their alloys. (20 Albert Embankment, London, S.E.11.)

Electricity in Industry, the **Lancashire Dynamo Group** technical review, contains an illustrated article on variable speed drives reviewing the development of equipment incorporating electronic and magnetic amplifier controls. (Victoria Embankment, London, S.W.1.)

Meetings

May 8.—Institution of Electrical Engineers (Technical College, Stoke-on-Trent, at 7 p.m.). "A Review of Work towards Nuclear Energy from Controlled Thermonuclear Reaction." D. W. Fry.

May 11, 12 and 13.—The Institution of Chemical Engineers, The Society of Instrument Technology, The British Computer Society (The Central Hall, Westminster). A Joint Symposium on Instrumentation and Computation in Process Development and Plant Design.

May 11-13—Institution of Chemical Engineers (Central Hall, Westminster, S.W.1). Symposium on instrumentation and computation in process development and plant design.

May 11-14—The Institute of Fuel (Palace Hotel, Torquay). "Second Liquid Fuels Conference."

May 21-27.—International Transistor Exhibition and Convention, Earls Court, London. Promoted by the Electronics and Communications Section of The Institution of Electrical Engineers.

Processes and Equipment

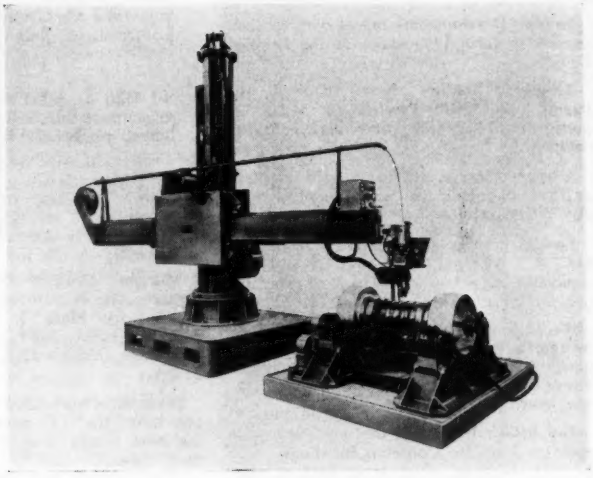
For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Welding Fabrications

The Lincoln L.R.C. travelling boom with revolving column is designed for use with automatic welding heads. The unit is particularly suitable for the internal and external welding of all types of vessels and similar fabrications. Mounted on a revolving column the boom is counter-balanced. The smooth travelling motion facilitates the welding of many different shapes of fit-up.

(Lincoln Electric Co., Ltd., Welwyn Garden City, Herts.)

1195



L.R.C. travelling boom with revolving column (Lincoln Electric Co., Ltd.).

Prototype Development

Capacity for the design, development and construction of prototype equipment at the works of P. and L. Miller has recently been increased and new design staff taken on. The works are well equipped to manufacture in any kind of material and the company has experience of many types of fabrication.

On a sub-contract basis, P. and L. Miller have made transformers, plastic extruders, high precision gear mechanisms, pressure vessels and a spiral conveyor system.

An associate company, Millers P.V.H.E. recently launched a new range of standard calorifiers with capacities of from 30,000 B.t.u. to 1,500,000 B.t.u.

(P. and L. Miller, Ltd., Heneage Street, Brick Lane, London, E.1.)

(Millers P.V.H.E., Ltd., Spelman Street, Stepney, London, E.1.)

1196

Fire Protection

Immediate warning of fire in unattended electronic equipment is provided by a new control unit introduced by the Minerva Detector Company. One or more Minerva detectors placed in the unit to be protected are connected to a 91C control unit. As soon as combustion products are given off by an overheated component the power supply to the equipment is interrupted.

(The Minerva Detector Co., Ltd., Lower Mortlake Road, Richmond, Surrey.)

1197

20-ton Mobile Crane

Shifting heavy equipment on site calls for a robust vehicle capable of operating even when axle-deep in mud. The new Jones KL 12-20 M crane which was recently publicly demonstrated at Letchworth will lift up to 12 tons free on wheels or up to 20 tons when blocked. Based on a four-wheel heavy-duty chassis, the drive to all motions is direct diesel. Steering is hydraulic and the brakes are air operated. A swinging front axle improves travel over rough ground, providing full traction at all times. Another feature of the KL 12-20 is high precision lowering—speeds of $\frac{1}{2}$ in./minute have been obtained with a 20-ton load.

(K. and L. Steelfounders and Engineers, Ltd., Letchworth, Herts.)

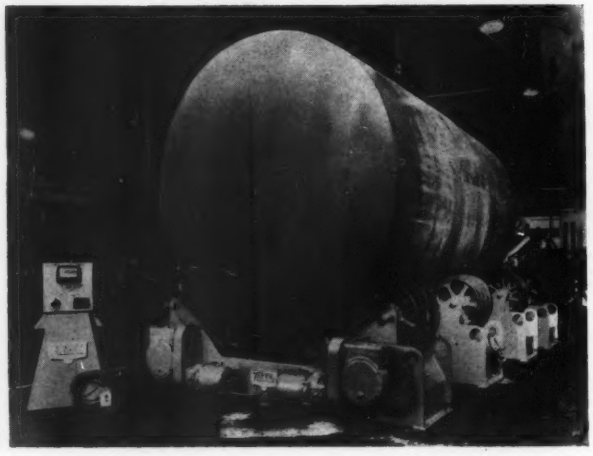
1198

Oxygen Profiler

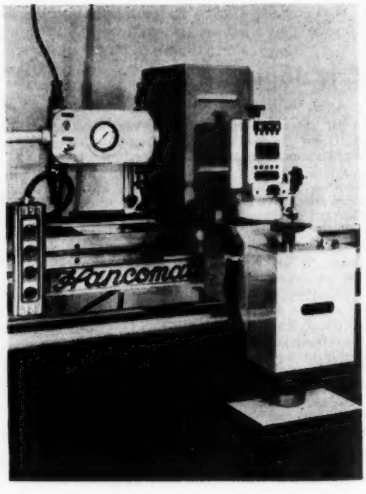
Hancock have recently introduced a new Hancomatic, a new dual carriage oxygen profiling machine. The unit has a new type of solenoid gas control valve which shuts off the cutting oxygen flow instantly on completion of the cut, avoiding any risk of nicking the profile as it falls from the parent plate. To ensure accuracy, wipers of sprung stainless-steel strip keep the main rails free of dirt and oxide particles; the rails themselves are of heavy rigid sections. A new improved tracer head, has been designed for use with conventional templates. Automatic push-button burner lighting is available on option with the machine.

(Hancock and Co., Progress Way, Croydon.)

1199



(Left) Yates 30-ton self-aligning rotator for automatic welding. The rotator incorporates a patented floating friction safety drive which prevents damage to gearing and motors when vessels are loaded on to the machine (Baker Perkins Ltd., Westwood Works, Peterborough).



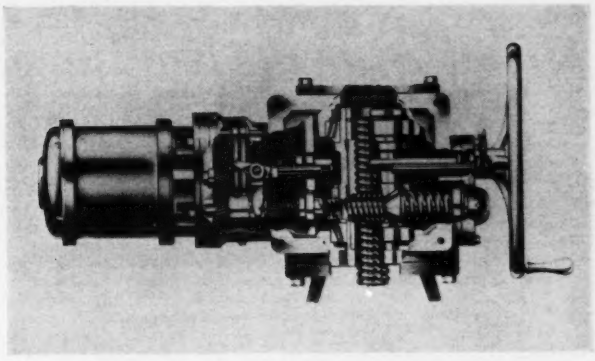
(Right) The new Hancock dual carriage oxygen profiler.

Valve Control Unit

To meet growing demands for the precision operation of valves, Opperman Gears (Holdings), Ltd., of Newbury have concluded an agreement whereby the LimiTorque Valve Control unit is to be manufactured in the U.K. by a wholly owned subsidiary company to be known as LimiTorque Valve Controls, Ltd. The new Company will be based on the Newbury works of Opperman Gears and will be able to call upon their special technical and administrative services.

To produce a power operated valve control with high torque and thrust capacities, high efficiency precision gearing is used. The first reduction is by helical gear and pinion. These are of heat-treated alloy steel, hobbed and shaved for accuracy, while worm and wheel make up the second reduction and final drive. The worm wheel is made from high tensile nickel bronze and the worm, carried on a splined shaft and retained in position by a spring, from alloy steel hardened and ground. Excessive torque drives the worm gear out of mesh and contactors stop the drive motor. Normally two contactors are provided for "full out" and "full in" limits, but intermediate positions can be fitted as required. Incorporated in the motor drive is a type of loose dog coupling arranged to allow the motor to achieve full speed before taking up drive in a new direction and imparting a "hammer blow" to the main shaft. This can be invaluable in unseating sticky valves after a long period of disuse.

A range of units is manufactured; type SMA, suitable for gate and globe valves, is available in six sizes with a maximum of 4,300 ft lb torque and 150,000 lb thrust whilst type SMA-HB, for butterfly and plug valves, has a maximum torque of 46,000 ft lb. Models are available with or without provision for manual operation. Type SA incorporates expansion compensation springs to ensure tight valve closure at all temperatures.



Cut-away view of one of the new Opperman LimiTorque actuators for controlling gate valves.

The bulk of the range of the control units being manufactured should be available for immediate delivery by the end of the year. *(LimiTorque Valve Controls, Ltd., Newbury, Berks.)*

1200

Reactor Periscope

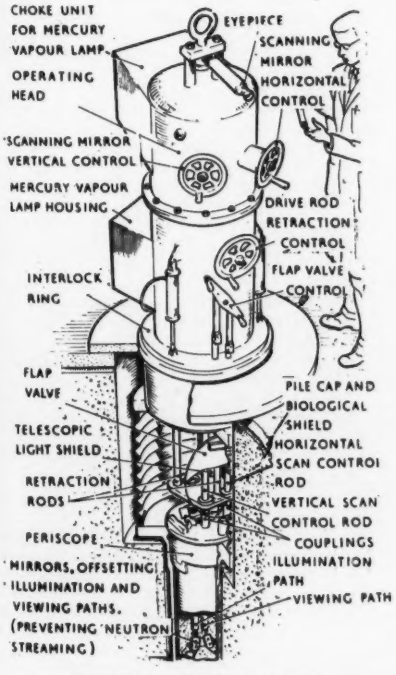
For power reactors a top dome viewing periscope has been devised by Vickers Armstrongs (Aircraft). This unit enables an examination to be made inside the dome of the pressure vessel. The fuel charging operation can also be observed. The unit is constructed in two parts, one containing the scanner head and image inversion corrector mechanism, located within the pressure vessel, and the other an operating head which houses the external control mechanism, the light source and the eye piece. The periscope can be inserted in the reactor by the fuel charge machine under low-power operating conditions.

The field of view is approximately 30-in. diameter at 12 ft distance from the scanner head with a magnification of 2 : 1. Vertical scan of the light path covers a field from a point 17 ft above the horizontal line of sight at 12 ft radius to a point below at 8 ft 6 in. radius. Continuous horizontal scanning through 360° is provided.

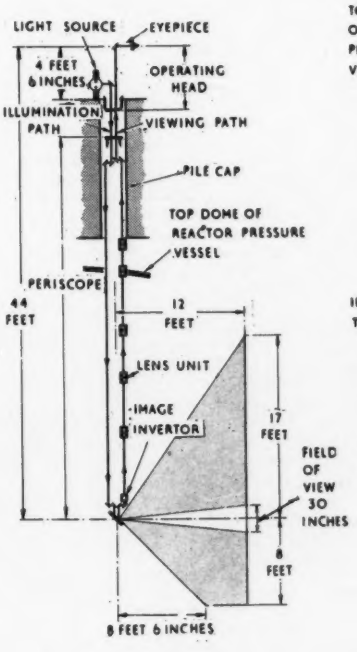
The light source consists of a high intensity mercury vapour lamp located in the operating head. The illumination light path is independent of that used for viewing and in order to project the light over the length of the periscope it is confined within glass tubing. The viewing and illumination light paths impinge simultaneously on the scanner-head mirror so that the concentrated light beam can cover the field of view in all positions of scan. Because of the stationary viewing position an image inverter corrector mechanism has been incorporated to maintain a vertical image.

(Vickers-Armstrongs (Aircraft), Ltd., South Marston Works, Swindon, Wilts.)

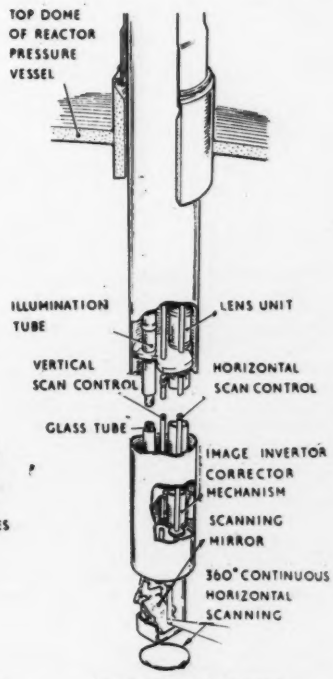
1201



Operating head and top of periscope.



Optical system. Top dome viewing periscope.



Lower portion of periscope

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 801,651. Atomic energy pile. E. D. Courant (Canada).

The pile has a core dimensioned slightly below critical size. The control members contain an amount of fissile material equivalent to at least 1.5% of their weight and larger than the amount of fissile material in the core substance. Initially, the control rods need only be inserted a short distance to bring the multiplication factor to a value exceeding 1. But, when the pile activity drops, the rods are inserted farther. The design is of particular interest in connection with breeder piles.

B.P. 801,743. Extraction of plutonium and uranium. U.K. Atomic Energy Authority (Canada).

An aqueous nitric acid solution, containing fission products in addition to plutonium in the tetravalent or higher state and uranium in the hexavalent state, is treated with a water-immiscible phase which includes tributyl phosphate.

B.P. 802,017. Liquid flow meters. L. R. Blake and British Thomson-Houston Co., Ltd.

The flow meter described is designed for measuring the rate of flow of an electrically conductive liquid such as liquid metal in an enclosed duct. A given length of duct is placed in a transverse magnetic field and arrangements are made to vary the field strength at a given intermediate point along that distance, such that current parallel to the flow of the liquid is zero at that point. When the desired field pattern has been obtained, the voltage is measured across terminals on either side of the duct at the measuring position. The voltage V_t thus measured is proportional to the mean velocity of the flow V_m according to the formula. $V_t = kV_m$ where k is a factor which depends on the internal dimensions and wall thickness of the duct, the resistivity of the liquid and on the magnetic field strength at the measuring position. This refinement eliminates the need for calibrating flow meters of this kind of design at several known rates of flow within the range the instrument is built for and, also, for calibrating the apparatus individually for the different liquids to be measured.

B.P. 802,043. Electromagnetic pumps. L. R. Blake and British Thomson-Houston Co., Ltd.

A number of conductors are arranged transversely to the duct carrying an electrically conductive liquid such as a liquid metal, in slots of the pole faces, and are interconnected individually or in groups as a magnetizing winding. This winding is energized by at least part of a current which is passed through the liquid. The conductors are so distributed in the slots that they produce the required gradient in the magnetic field.

B.P. 802,086. Manufacture of composite bodies, comprising a metallic component and a component of porous material. J. J. Norreys and General Electric Co., Ltd.

A graphite block is placed on the surface of an article of mild steel or low-alloy steel and a load of two tons/sq. in. is applied to the graphite block. The assembly is heated in an atmosphere of pure carbon dioxide at 575°C for 200 hours. A strongly bonded composite body is obtained as a result.

B.P. 802,147. Uranium alloys. A. U. Seybolt.

Pure uranium corrodes rapidly and shows low mechanical strength. In order to overcome these drawbacks, alloying with other elements has been proposed in the past. Alloying with heavy elements may result in an increase of the slow neutron capture cross-section and alloying with light metals has often caused undesirable nuclear reaction phenomena. There is thus a severe limitation on the materials that can be used as alloying elements. It is claimed in the present patent that a uranium alloy containing 0.1-10% by weight of zirconium or columbium will give a satisfactory fuel material for use in reactors, in quantities not appreciably larger than that of pure uranium, the compound showing considerable increase in corrosion resistance and hardness, which in the case of a 5% columbium alloy, would rise after suitable heat treatment to 71 Rockwell A, as compared with 50 Rockwell A for pure uranium. Both elements, zirconium and columbium have a neutron capture cross-section at thermal energies below that of natural uranium.

B.P. 802,285. Nuclear reactor fuel element handling plant. W. R. Wootton and Babcock and Wilcox, Ltd.

Details are given of a reactor servicing machine which facilitates the removal of a fuel element from its operational position by passing it down a disposal tube, in which a head of liquid is maintained in order to limit the velocity of descent. The lower end of the disposal tube is submerged in a liquid held in a pressurized chamber and its position is adjustable to facilitate loading the discharged fuel element into a truck, by means of which it is withdrawn from the pressurized chamber through a pipe fitted with a gate valve to a general storage reservoir for disposal by normal transport.

B.P. 802,470. Production of beryllium. L. J. Derham and U.K. Atomic Energy Authority.

Reference is made to B.P. 781,100 describing a method of producing beryllium whereby previously crushed beryllium fluoride and finely divided magnesium are compacted in stoichiometric proportions into briquettes of about 2 in. diameter and 1 in. depth, the briquettes are placed into a bath of molten calcium chloride, the vessel holding the calcium chloride being sealed afterwards and the contents being heated at elevated temperature for a period of one to two hours. Subsequently, it has been found that the success of the method is not restricted to the use of molten calcium chloride as a material for the bath. According to the present application other suitable melt materials are: magnesium chloride, sodium chloride, mixtures of sodium and magnesium chlorides, mixtures of beryllium and calcium chlorides and mixtures of calcium and sodium fluorides.

B.P. 802,552. Reactions involving irradiation. Esso Research and Engineering Co. (U.S.A.).

A method is described whereby organic materials are irradiated in the presence of a solute which, on neutron capture, emits an appreciable amount of alpha particles of high kinetic energy. The presence of such an accelerating solute was found to promote effectively the radiochemical conversion of the reactant. The results of the method are particularly beneficial in hydrocarbon conversion processes as carried out in a nuclear reactor. Among suitable accelerating materials, boron-10 and lithium-6 are of primary interest.

B.P. 802,555. Electrolytic separation of isotopes. Soc. d'Electro-Chemie, d'Electro-Métallurgie et des Aciéries Electriques d'Ugine (France).

Various electrolytical methods are in use for the separation of isotopes. All use uniform direct current and in the case of amalgamable metals such as lithium, a continuously renewed mercury cathode is provided to remove the metal from the electrolyte. This arrangement can be employed for the separation of lighter and heavier isotopes from a liquid electrolyte, derived from an isotope element such as lithium, by applying a square pulsed voltage at intervals across the electrodes of the electrolytic cell. Under the action of the pulse, the various isotopic ions reach different velocities and, as a result, the ions of the lighter isotope concentrate in the region of the cathode. By arranging for the rapid removal of the ions at each pulse the proportion of the lighter isotope in the mixture withdrawn from the electrolyte is increased. At the same time the proportion of the heavier isotopes in the remaining electrolyte rises accordingly. If the operation is continued for a sufficiently long period, progressive enrichment will result in complete separation. Details of the method and results obtainable are given for the separation of Li-6 and Li-7 using a saturated aqueous solution of lithia as the electrolyte.

B.P. 802,805. Nuclear reactor fuel elements. Babcock and Wilcox, Ltd. (Germany).

In order to ensure uniform heat transfer, a sheathed fuel rod should have contact with the sheath over as large a surface as possible. Where such contact is restricted to a few points, there is a danger of overheating. In order to overcome this risk, it is proposed to employ rods of comparatively small diameter and to position same in the axis of the sheath employing spacers, such as bosses, ribs or distance rings. The spacers should be made of non-fissile material with a melting point higher than that of the material of the rod or the sheath.

B.P. 802,806. Nuclear reactor fuel elements. Babcock and Wilcox, Ltd. (Germany).

The fuel elements are designed to fit cylindrical apertures in the moderator body. Their sheaths have external projections which keep the fuel elements clear of the surrounding moderator material. The space between sheath and moderator provides a passage for the coolant.

B.P. 802,938. Cooling of nuclear reactors. R. A. Gustison and Union Carbide Corporation (U.S.A.).

The fuel elements are immersed in a bath of liquid niobium pentafluoride connected to a heat exchanger. Niobium pentafluoride can be used at a higher temperature than water and no pumping difficulties arise as would be the case with alkali metals. Standard heat-transfer units can be employed. No special corrosion-resistant materials need be used in construction.